

Contract #H-2316

VOLUME II
INTERIM TECHNICAL REPORT
FIRE SAFETY SYSTEMS
ANALYSIS FOR RESIDENTIAL
OCCUPANCIES:
TECHNICAL SUPPLEMENT

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LIST OF ABBREVIATIONS

BFM	- Building Firesafety Model
DT	- Decision Tree
FDM	- Fire Development Model
FSOC	- Firesafety Objective Component(s)
FSOCL	- Firesafety Objective Component Logic
GSA	- U. S. General Services Administration
HRM	- Human Response Model
HUD	- U. S. Department of Housing and Urban Development
MPS	- Minimum Property Standards
NFPA	- National Fire Protection Association
PCL	- Parameter Conversion Logic
P_F	- Probability of Failure
P_{FSOC}	- Probability of Achieving Firesafety Objective Component
POC	- Products of Combustion
POCM	- Products of Combustion Model

This report details the development of a model for estimating and comparing the levels of fire safety for alternative design configurations. The model is designed to permit estimation of equivalency* of firesafety levels obtained from design alternatives to the Department of Housing and Urban Development Minimum Property Standards (HUD/MPS). The model was developed using the systems approach, whereby the interaction of all the structural components are considered rather than individual component specifications. In order to demonstrate the feasibility of the systems approach, a test was developed using the MPS for One- and Two-Family Dwellings (4900.1). This approach will later be extended to the MPS for Multifamily Housing (4910.1)⁽⁵⁾, Care-Type Housing (4920.1)⁽⁶⁾, and the Federal Mobile Home Construction and Safety Standards⁽⁷⁾.

The heart of the systems approach is a fire development model which simulates fire growth utilizing a state transition model. Fire behavior is also simulated as well as the interaction of fire behavior with human response. The addition of building design parameters, fire safety objective components, and products of combustion result in a complete interactive model which is termed the Building Firesafety Model (BFM).

The BFM is briefly described in Volume I and described in more

plains how the BFM and the systems approach are related. All in the report are the results of the test to demonstrate the of approach. Finally the relationship of the MPS to the systems approach is discussed.

EXECUTIVE SUMMARY

This report details the findings of Phase I of a task which is being conducted to develop a systems approach of the relative firesafety levels of alternative designs, especially with regard to the establishment of equivalency to the Department of Housing and Urban Development's Minimum Performance Criteria (HUD/MPS) for residential occupancies.

Volume I is a report to "users." Included as "users" are:

- HUD officials - the acceptance authorities who will evaluate the systems approach and the equivalency tests
- Designers - the architects and engineers of the buildings

Readers are invited to correspond with the project staff regarding potential uses and important design alternatives to be investigated.

Volume II of this report is written primarily for fire protection engineers who wish a more detailed technical description of the model, the simulation process, and this particular application of state transition models. It is hoped that the data contained herein will help others in planning their research efforts and encourage further dialogue.

Decision Tree (DT) (Figure 1-1)⁽¹⁾ was used. The DT is based on the pioneering work of the U.S. General Services Administration in the same area.⁽²⁾ It has been assumed in the research that the DT represents the important factors in the prevention and control of building fires.

Efforts to utilize the Decision Tree resulted in many problems in its direct application. These problems stemmed from a lack of sufficient knowledge of the DT elements which in turn led to an inability to formulate the mathematical mathematics of the Tree. This conclusion is one of the important findings of the study since it had been assumed that the DT could be directly applied.

The result of the inability to apply the Tree directly required the development of a computer model of fire growth and development based on the systems approach. The computer model is based on a state transition model of fire growth which breaks up the fire development into states, called "realms," and assigns a set of rules by which the fire progresses from one realm to another. This model is broken down into components, each of which simulates a different portion of fire development. These components are:

These tests involved the reaction of the model to varying types of behavior for finish. In these sensitivity tests the computer model reacted predictably, which is an indication that this model works as anticipated.

The sensitivity tests were also used as the basis for a comparison of the products of this contract to the evaluation of the design. In this example, the cost versus firesafety issue was addressed. The example only utilized a change in a single factor but it indicates how one of the model outputs may be used.

Throughout Phase I, an extensive literature search was conducted to collect supporting data for the problem analysis and the model development. As an aid to those who are working in the field, a literature review is included in Appendix D of Volume II. A discussion on the methodology of this literature search appears in Appendix C, Volume II of the report.

In summary, the results of this phase of the study are:

- The development of a systems approach to the evaluation of fire safety
- A computer simulation to provide quantitative evaluation of fire safety
- A demonstration of the feasibility of this system

ACKNOWLEDGEMENTS

The work presented here could not have been completed without the help and cooperation of many people. We especially thank:

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CHAPTER I

INTRODUCTION

A quantitative measure of fire safety indicating the degree of safety for people in a building, for the building, and for the building contents, is an essential requirement for those professions carrying fire protection responsibilities. Fire safety is usually an extremely complex and complicated function of many factors including fire prevention, fire growth, fire suppression, and human behavior. Such factors include all of those associated with the life of the building from inception through construction and, finally, to building use. The experience in developing a quantitative measure is that it will permit economical design (or redesign) of buildings with an appropriate level of fire safety, since the measure will allow knowledgeable design options to be evaluated in terms of cost/safety factors.

The purpose of the study discussed in this volume is to evaluate a particular building standard, the Dept. of Housing and Urban Development (D) Minimum Property Standards (MPS). This evaluation is to be

Evaluation of the Decision Tree

In order to organize a systematic approach to the quantitative assessment of fire safety, the National Fire Protection Association (NFPA) Systems Concepts Committee developed a logic tree which delineates the relationships of fire protection system elements. The Decision Tree* (DT) in its present form (1974 edition) incorporates what is believed to be all possible factors for preventing or controlling fires. The Tree serves as a framework for the development of a quantitative evaluation of fire safety. However, application methodology using the DT to the direct evaluation of fire safety in particular building types has proven difficult.

The difficulty stems from the structure of the Tree, as well as the nature of the elements. The elements in the tree are general in nature (lack specificity) and, therefore, are difficult to assign probabilities to directly. For instance the element entitled "Contain and/or Confine Fire" is not an event but a collection of possible events. Examples of these elementary events would be whether doors and windows are open or closed, or whether a heating, ventilating, or air conditioning system is operating. These events can be assigned probabilities but the Tree does not delineate which of these elementary events correspond

estimating the relative contributions of the various events. The success tree does not do this.

The structure of the Tree also presents a problem. The Tree has already been described as a success tree which is a static solution to a dynamic problem. That is, whenever some level of success is achieved by a specific combination of elements, a specific level of fire safety will be achieved. Fire growth and development is a time-oriented process and such many objectives may not be met (such as attaining life safety) although at some point later in the fire all the DT elements need to be reached for this goal may be fulfilled. By using a tool which is dynamic in design, it is possible to develop a method which will assign weights to the elements in the tree and also consider the effects of combinations of elements and combinations of events.

Finally, Boolean logic implies that only certain paths are needed to meet the objectives of the success tree. This may well not be true. Other paths, not indicated by Boolean logic, may prove even more important. That is, Boolean logic may be the wrong model for combining elements of the DT.

This discussion of the difficulties of direct application of the Success Tree does not mean to imply that the DT is invalid or that it is not a useful tool. The DT is a useful tool and essentially all of

Therefore, our research team has developed a dynamic model that combines the DT elements with the intent of learning how these elements be combined when estimating levels of success in meeting fire safety objectives. However, the research team holds open the final decision as to whether or not the Boolean logic of the DT must be altered to better describe how the elements combine to produce various levels of fire safety.

Fire safety is defined in terms of components for which probabilities and probability values can be determined. The following firesafety Objective Components (FSOC) have been established:

1. Life safety for people who are capable of self-preservation.
2. Life safety for people who are nonambulatory, infantile, senile, or otherwise incapable of self-preservation.
3. Protection of structure (building).
4. Protection of utilitarian value of facility (mission).
5. Protection of contents of structure.
6. Protection of community (i.e., of community exposure from effects of a fire in the structure).

Assume for a moment that methods of applying the DT are known. Given the capability, how could the HUD/MPS be evaluated? One way is suggested in Figure 1-1 in which the influence of the MPS on building parameters is determined and a set of building parameters satisfying the MPS are input to the DT. As illustrated in Figure 1-1, probabilities of satisfying firesafety objectives (P_{FSOC}) are determined using a Decision Tree. With this concept, a building design consistent with the MPS can be evaluated with regard to fire safety.

The effect on fire safety of one or more MPS specifications could be determined by comparing the probabilities of satisfying firesafety objectives from those

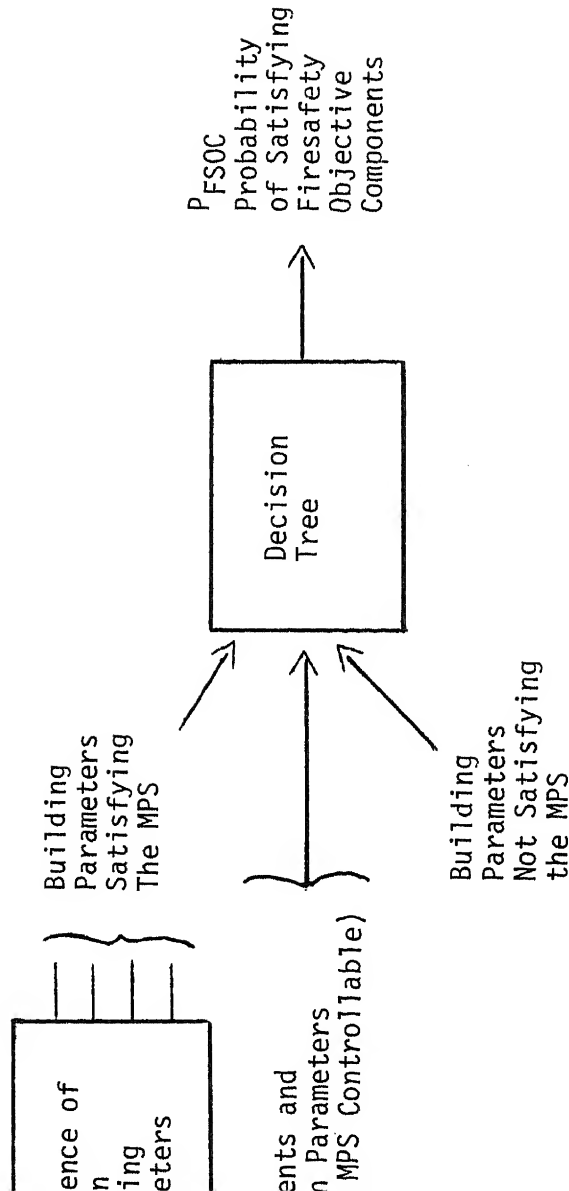
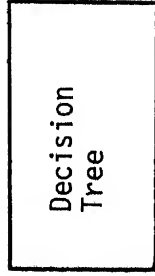


Figure 1-1 Method of Evaluating MPS

from that obtained when there was no MPS violation. The problem then is to develop a method for applying the DT. In order to solve the problems in applying the DT discussed previously, an alternative representation of fire development as suggested in Figure 2 must be developed. This alternative representation must use the same inputs (building, contents, and human parameters) and provide the same outputs (P_{FSOC}) as the Tree. Analysis of the alternative representation can show how to use the Tree. Perhaps it can show how to revise the Tree to make direct application possible. This alternate representation is termed "Decision Tree Model".

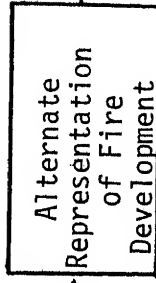
There are several similarities between the DT and the DTM. Most notably, the inputs and outputs are somewhat similar. Inputs to the DT are, at the present time, parameter categories (e.g., provide for ventilation); inputs to the DTM are the quantified variables (e.g., total window area = 10ft²) of those categories. The major difference is that the internal logic of the DT is general while the logic of the DTM is specific to a given occupancy type. Thus, the DTM logic can be thought of as that of the DT with any irrelevant logic removed.

Building, Contents and
Human Parameters



Probability of Satisfying
Firesafety Objectives

Building, Contents and
Human Parameters



Probability of Satisfying
Firesafety Objectives

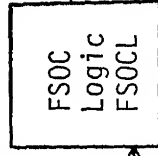
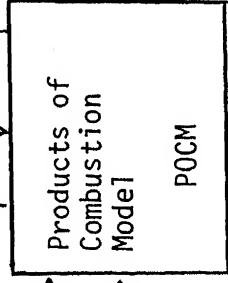
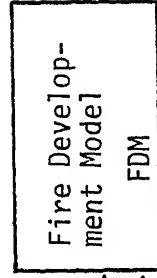
Development of a DTM for a specific application requires data and quantitative answers to questions. Such questions concern the extent of fire development, the amount and dispersion of the combustion products, and the interactive impacts of people and fire. Since no complete theory or data base is available to answer these specific questions, a means is necessary to represent what is known about fire dynamics. A Building Firesafety Model (BFM) representing fire development, combustion products generation and movement, and the interactive effect of people and fire can satisfy this need. With the BFM, specific types of fires can be represented in specific types of occurrences and questions as to probability of a given extent of damage and probability of injury or death can be answered.

What is the difference between a DTM and BFM? The answer is detailed in the description of the BFM presented in Chapter 2. Essentially, the BFM is a dynamic computer model and represents many functions of fire growth and spread. In contrast, a DTM is a static algebraic equations (or tables and graphs) representing the relationship between building parameters and P_{FSOC} .

A block diagram of the BFM is shown in Figure 1-3. This diagram includes several component models and logic:

Building Fire Generation Logic (BFL)

Quantified
Parameters



Fire Dynamics

Human
Actions

Products of
Combustion

Dynamics

P FS

Development Model represents fire growth and spread while the Production Model represents generation and spread of smoke, heat, and toxic gases. The Human Response Model represents the action of people involved in the fire - including the effect of people on the fire development. The FSOC logic accepts inputs from each model and determines the probability of success for each firesafety objective combination. Evaluation of a particular building design would proceed with inputting building and furnishing parameters, and information about the individuals in the building. The output of the models would be calculations of P_{FSOC} values.

The parameter conversion logic relates a building design to probability of fire initiation, growth, and spread. Such logic can be developed from several sources:

- fire incident data
- fire test data
- case histories
- fire theory
- professional judgement of fire protection engineers
- combinations of the above factors.

The conversion logic can be specific and apply only to one building type, or it can be general and apply to a class of building types. Ideally,

part of the BFM and consistent with the purpose of the BFM, the model represents what is known about fire development as a function of building parameters, contents, and human parameters. On the other hand, if there is uncertainty of varying burning rates, then a distribution of fire development parameters for given sets of human, contents, building parameters must be developed and the parameter conversion logic must represent this distribution. Fire Development and Human Response Models were developed and evaluated in the Phase I effort. These models are described in detail in the subsequent chapters of this report.

The first step in FDM construction is to identify significant conditions of the fire development, such as "first material (only) involved, room of origin fully involved." A complete set is discussed in Chapter 2. Dynamics of the fire development are represented by the probability of time a certain condition exists and the probability of changing from one condition to another. These dynamics are determined by the characteristics of the fire environment. Also represented is the effect of human actions on fire, e.g., manual suppression by people involved in fire or fire department personnel.

The HRM was developed in an analogous way in which the human location and actions are represented along with the change in location and actions of the fire development.

C is included in Appendix D of this volume. A discussion on the methodology of this literature search appears in Appendix C of this volume.

Conceptual Description of the Models and Their Potential Use

A model merely represents what is known about a subject. If the value of a variable is known, the value is entered into the model. If a value is not known but its distribution is known or can be estimated, that distribution can be entered into the model, and so forth. The use of the model allows one to ask questions and get answers which may or may not be correct, to the degree the model represents the real situation, the accuracy of the questions posed. In this sense, the models provide an "accounting" of the result of combinations of complex factors which are not easily envisioned without the model. It is the accounting or manipulation of the data which makes the model useful. For instance, to quantitatively evaluate the effect of a particular factor or to estimate the benefits from a proposed solution.

In the case of the Fire Development Model (FDM) to be described, the objective is to represent in a very simple form each of the factors which are believed to affect fire development. The lack of an overall fire development theory and the spottiness of data suggests that a simple type of model should be utilized for at least the initial investigations.

ia for that realm as opposed to changing to conditions which sa
ther realms.

ire conditions selected for one/two family homes are as fol-

- no fire
- first material is involved
- second material is involved
- room is fully involved
- second room is involved
- floor of origin is fully involved
- floor beyond origin is involved (in dwelling of origin)
- dwelling is fully involved

he occurrence of a critical event has long defied prediction. T
er for the model to simulate fire development, a non-determinis
(a deterministic model accepts as input a set of initial condit
uniquely determines the output) had to be developed. Probabili
provided a possible solution. In a probability based (or stoc
model, the changes from realm to realm are called transitions
signed a probability (likelihood of occurrence). For instance,
n which the second material has become involved might have a pr

ore a critical event occurs which demands a change in realm. These
times are directly related to a particular transition. For example
the mean time for a transition from the second material involved (realm 2)
to full room involvement (realm 3) might be five minutes while the
mean time for a transition from the second realm to the first realm
(first material involved) might be one minute.

In order to determine the transition probabilities and mean realm
times, several routes can be taken. Experimental data and professional
judgement all play a part. However, the probabilities and mean times
are not directly available so judgements as to the distributions of
realm times and transition probabilities had to be made. For realm 2
the times were distributed according to a geometric distribution. Pro-
fessional judgement was used to generate transition probabilities.

An example of how the transition probabilities and mean realm times
used may be useful. In a room fire the temperature grows for a
period of time, reaches a peak and, if the fire has not spread to new
levels, finally drops off. Test data often yields a temperature histo-
gram that is symmetric about the peak. This would lead us to the conclusion
that at a fire, where only the first material was involved, would have mean
transition probabilities of transition to a second material and to self-extin-
guishment. However, the mean times for transition to the second material

able in attempting to suppress fire, changing the configuration of the building (e.g., closing a door) communicating with other people (e.g., alarmers in the building, notification of fire department, etc.), and the movement of people can be modeled.

The coupling between one part of the model and another, such as the effect of the portion representing human actions on the portion representing fire development, is included by representing the effect of the human actions on the realm transition probabilities. Likewise, the effect of a human response on a fire is represented by the effect on the probability that the human will select a certain initial action to follow it by another action. For example, given that only the material is involved (a small fire), there is a relatively large probability that humans will respond to the fire site, then obtain suppression tools, then attempt suppression. But, given a large fire, the probability will certainly decrease.

Operation of the model proceeds from an assumed initial realm and assumed initial location(s) of the humans involved in the fire. After the operation commences in which, for each successive time interval, fire development (realm transition) and human response (actions) are calculated according to the probability distributions established.

Assumptions include the effect of one part of the model on the other.

ent will follow the rules established by the time distributions and transition probabilities as affected by the interaction of one port with the model with another. However, we are not interested in examining the development, i.e., one "movie," but instead, are interested in computing the statistics of many likely developments. For example, one firesafety objective component involves the damage to the building. For a given type of fire initiated, the amount of damage to the building may be identified by the extent of fire growth in the building. Thus, the probability that the fire development will exceed a certain growth may be computed directly from multiple runs of the Fire Development Model. In this way, the effects of variations of any variable on achieving success in any firesafety objective are computed.

Applications of such a model, which is a very simple model, can be very extensive. The application of interest here is the evaluation of the probabilities of success of achieving each firesafety objective as a method of determining the firesafety level of a design or structure. However, the BFM can be applied to many other areas. For instance, it could be used to evaluate the impact of a new firesafety standard. The BFM can be adapted to the distributions of fire developments in a given community (conflagration potential). Also, the BFM can be

ponses that affect fire development are discussed in the next section and a combined model is described in a later section.

The purpose of the FDM is to establish fire conditions (termed realms) as an aid in computing probabilities of success (P_{FSOC}). Establishing the FDM realm as discrete fire conditions has several benefits. First, calculation of P_{FSOC} can be accomplished on a realm basis - each being a distinct case. Second, the fire dynamic properties (realm time and transition probabilities) can be determined from available data sources. Third, the model concept is easily understood whereas the method of calculating realm time and transition probabilities may be complex. Therefore, this ease of understanding may aid in widespread acceptance and use of the model versus a more abstract approach.

It is generally agreed that fire development can be divided into stages but that the dynamic fire properties are variable - a function of realm time. For example, the probability of transitioning to a higher realm time. How can a fire spread may be a function of realm time. How can a dynamic time-changing process be represented by a fixed set of probabilities and transition probabilities? The answer used in developing the FDM is that the process can be represented to any degree of fidelity simply by subdividing the realms into sub-realms. In showing

- Determine realm times and transition probabilities for each realm

first two steps identified above are described in this section. Since realm times and transitions are affected by human actions, the development variables are established in a combined model.

Typical Fire and Fire Location for One- and Two-Family Dwellings.

Information about the types of fires occurring frequently in one- and two-family dwellings is required for input to the fire development and human response models. Specifically, the types and locations of fires, frequency of occurrence, and location of people at time of fire, etc., are required.

A set of fire types is shown in Table 2-1 and is used as a working basis. Also indicated is the relative location of the fire and dwelling occupants.

Both flaming and smoldering fires were considered in each of the twelve fire scenarios. These two fire types have different effects on the mean time for transitions between early realms. The mean will vary according to the type of fire being considered. For example, in a living room fire (type 10), the mean time for a transition from realm 1 to realm 2 is 3 minutes for a flaming fire. When considering a smoldering

Location of Dwelling Occupants
of Ignition

Location of Ignition in Dwelling	First Material Ignited	Location of Dwelling Occupants of Ignition			
		Area of Origin	Room of Origin	Exit	Floor Origin
Basement	Wood, Paper				
Basement	Wood, Paper			X	
Bedroom	Wood, Paper	X			
Bedroom	Wood, Paper		X		
Bedroom	Wood, Paper				
Kitchen	Fabric	X			
Kitchen	Fabric		X		
Kitchen	Fabric			X	
Bedroom	Fabric	X			
Bedroom	Fabric		X		
Kitchen	Food	X			
Kitchen	Food		X		

head and the probabilities of transition from one realm to another. The selection of realms is influenced by data availability and the purpose of the model - only those realms required for calculating the P_{FSOC} for achieving firesafety objectives need be defined.

Realms exist for a time interval and begin with an event termed "critical event." A critical event occurs at the first instant a specified fire condition is satisfied. A critical event is used further to identify the fire condition necessary for the start of a realm. The continued existence of a realm depends on whether or not the fire condition satisfied criteria for possible subsequent realms.

Fire conditions selected for one- and two-family homes were as follows:

- No fire
- First material is involved
- Second material is involved
- Room is fully involved
- Second room is involved
- Floor of origin is fully involved
- Floor beyond origin is involved (in dwelling of origin)
- Dwelling is fully involved

Consider the three possible combinations of first and second materials involved in fire:

- First material involved and not the second,
- First and second material involved
- Second material involved but not the first.

Depending on the purpose of the model, one, two, or three realms may be defined to represent the two-condition fire involvement process.

A logic to convert the conditions to describe fire realms requires three functions: "true," "false," "don't care." As defined in Figure 2-2, logic for each realm specifies that certain conditions be true, false, or that the logic "does not care" if the condition is true or false. For example, the logic for Realm 0 (no fire) requires that all conditions be false. While the logic for Realm 2 requires that "first material involved" be true and all other conditions be false except "second material involved." The logic "does not care" applies to "first material involved."

Figure 2-1 illustrates a likely fire realm sequence where there is no automatic or human detection of fire and, therefore, no suppression activity initiated. The figure illustrates the transitions that are likely to occur from one realm to another by arrows. For example, transitions from Realm 3 (Room is Fully Involved) are to Realm 4

the Fire Development Model.

alms

0	0	0	0	0	0	0
1	1	0	0	0	0	0
2	-	1	0	0	0	0
3	-	-	1	0	0	0
4	-	-	-	1	0	0
5	-	-	-	-	1	0
6	-	-	-	-	-	1
7	-	-	-	-	-	-

0 False

1 True

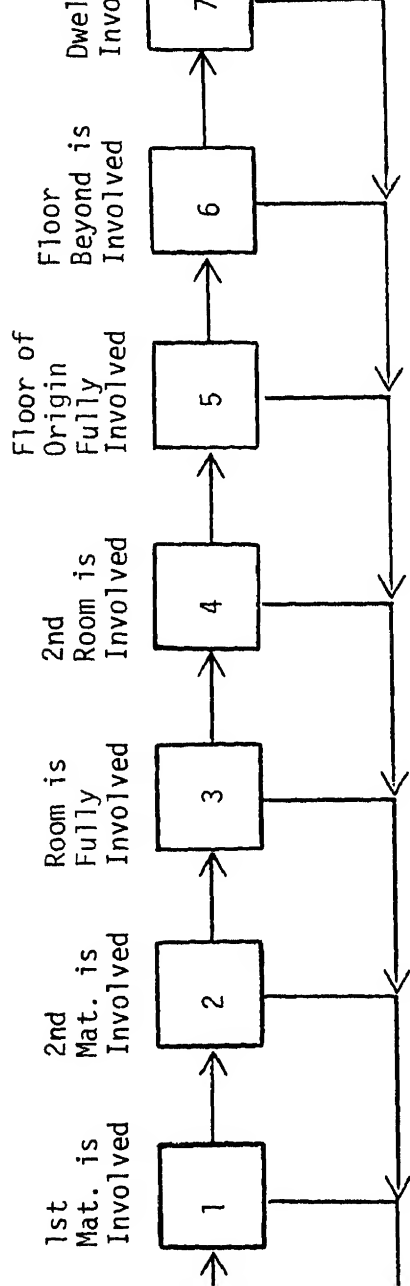


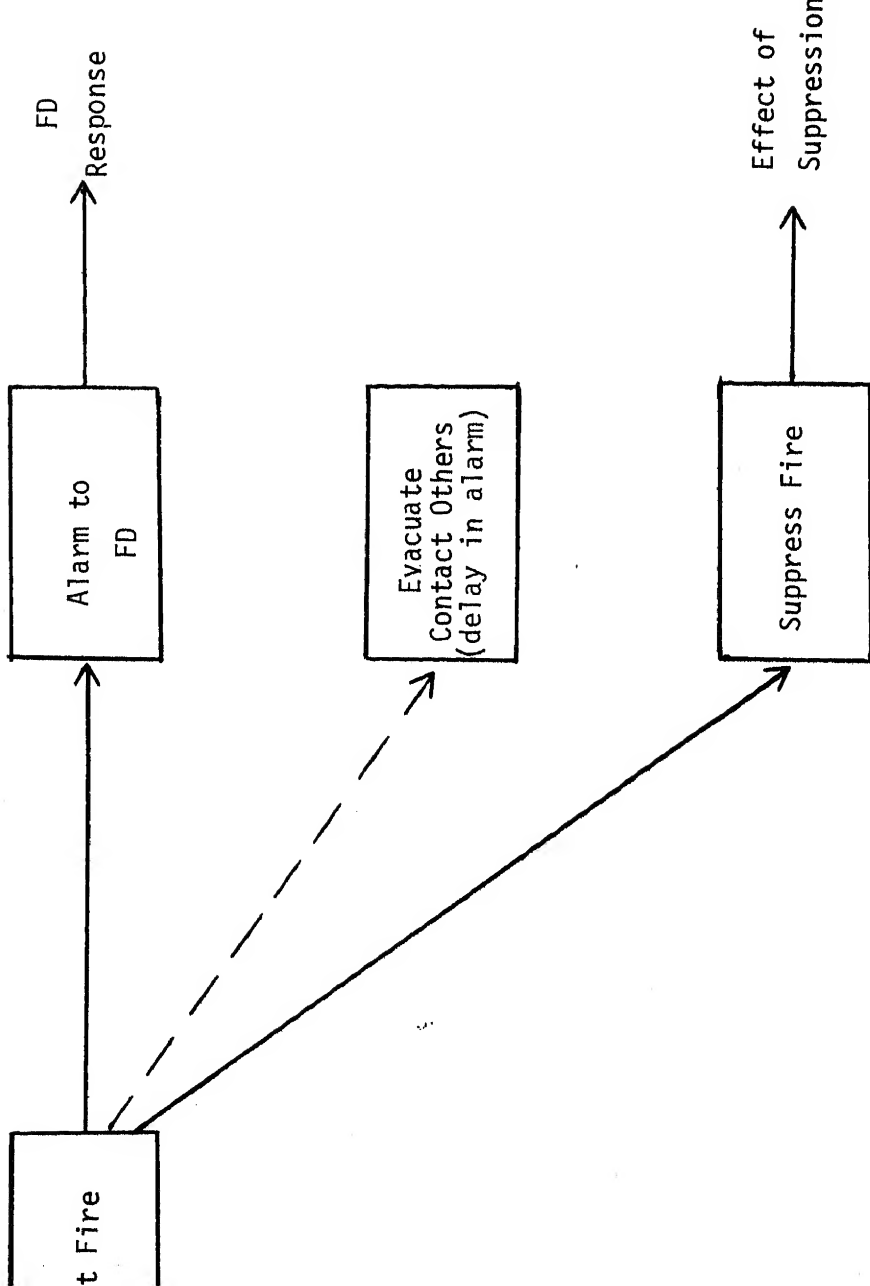
Figure 2-1 Likely Transitions for One/Two Family Dwellings

way process in which humans affect the ignition and growth of fire and fire and combustion products affect humans. These two effects are described separately in the models of human response (HRM). The effect of fire on humans depends in part on the relative location of the fire to the persons. The HRM is therefore developed to represent the actions of all individuals involved in the fire.

In order to represent the effect of human actions on fire development, consider a simple model of the actions of the first individual detecting the fire, illustrated in Figure 2-2. The set of possible fire actions is taken as: Suppress Fire, Evacuate, or Alarm to Fire Department. An alternative "take no action" was classified as "no detection" and that portion of the HRM representing the impact of humans on fire development. Also, if an individual evacuates without attempting fire suppression without notifying the fire department either before or after evacuation with respect to fire development, those actions can also be classified as a "no detection."

"Alarm to Fire Department" can be taken to include notification as a first action and also notification after evacuation. As a result, the effect of the human response on the fire is modeled with two

- Alarm to Fire Department

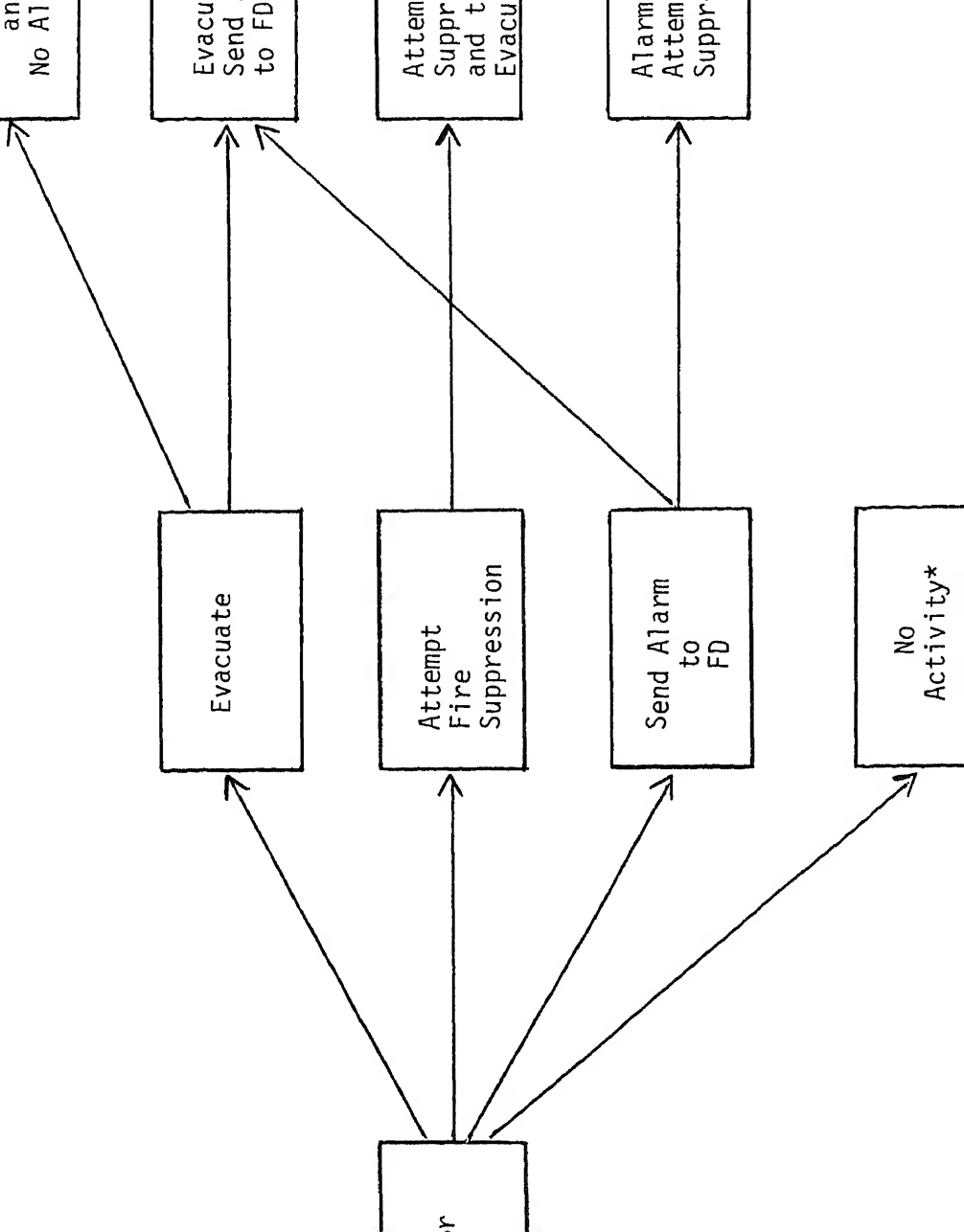


The model presented above can be expanded to form a more complete model reflecting the activity of all individuals involved in the fire. This includes the actions of the individual(s) affecting the fire described above. As shown in Figure 2-3, the first action of individuals who detect the fires, are alerted to the fire, or are alerted to the fire is represented as one of the following:

- Evacuate
- Attempt Fire Suppression
- Send Alarm to Fire Department
- No Activity

Note that "No Activity" is similar to not being alerted, not detecting the fire, or not reporting the fire.

Second actions stem from the first. For example, an individual can either evacuate without giving the alarm or can evacuate and notify the fire department. This latter condition is combined with notifying the fire department and then evacuating as discussed in the previous paragraph. Alternatively, the individual can evacuate attempting fire suppression which may or may not have been successful. If the fire suppression is successful, the fire realm changes to "Fire." If the individual attempts fire suppression and then evacuates, the implication is that the fire suppression activity was unsuccessful.



location of the individual with respect to the fire and the existing fire realm. A set of relative locations includes the following:

- room of origin
- floor of origin
- exit
- floor beyond room of origin
- other dwelling unit
- outside dwelling of origin

Relation of Model and Decision Tree "Manual Suppression" Branch.

The HRM described above employs logic from the "manually suppress fire" section of the Decision Tree (DT). The DT identifies six actions which are combined by AND logic to designate the actions required to manually suppress a fire. These actions are:

- detect fire
- communicate signal
- decide action
- respond to site
- initiate suppressant
- control fire

The HRM described above uses only some of the responses as i

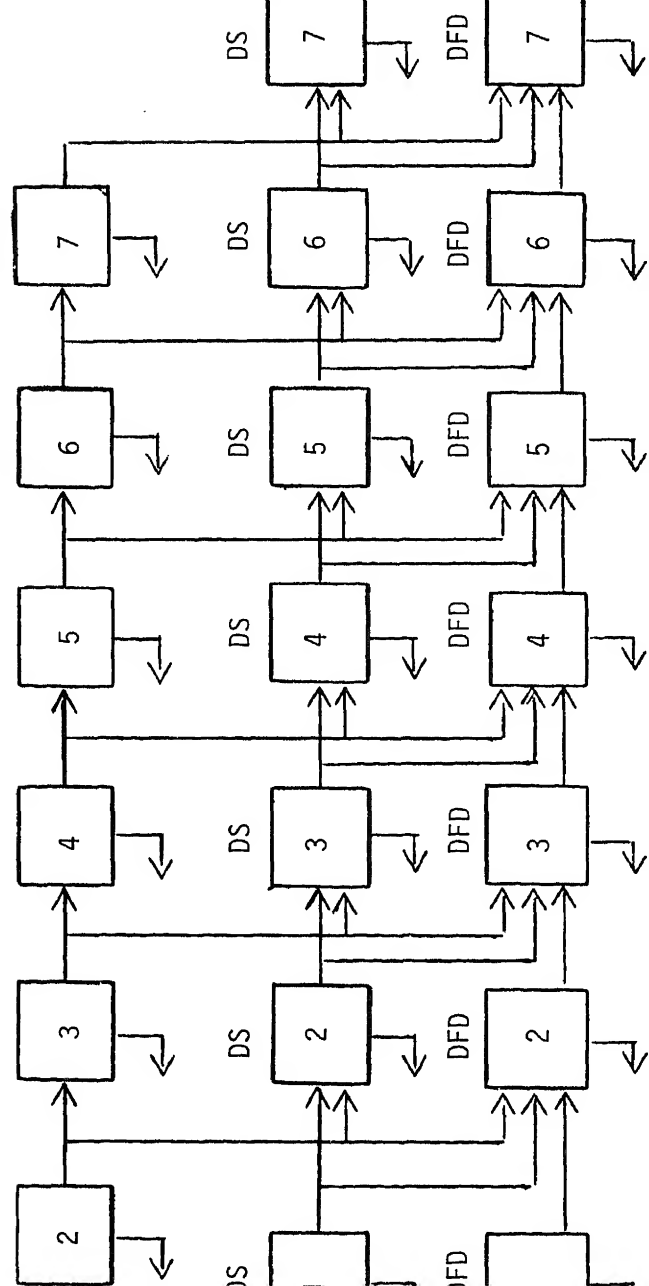
sant" of the DT are combined in the modeled human action: Notification of the Fire Department. Thus, the logic for manual fire suppression, as defined by the Decision Tree, is used directly in the Human Response

The models for fire development and human response described in the previous sections can be combined to represent fire development and extinguishment with human intervention in one- and two-family dwellings. The fixed FDM structure, as defined by the realms selected, is required to represent types of fires (as defined in Table 2-1), but some model variables (realm time distributions and transition probabilities) must be adjusted to represent fire development for each combination of fire type and fire location.

In order to represent the effect of human actions on the fire development, the fire realm is combined with human actions to include the effect of fire detection, fire department response, and occupant suppression. For the cases shown in Figure 2-4, the realm/action combinations associated with the "First material involved" are:

- First material involved, fire not detected
- First material involved, fire detected, and manual suppression initiated by occupant
- First material involved, fire detected, and the fire department responded

The set of realm/action combinations associated with the "Second material involved" are:



D No Fire Detection
 DS Detection and Occup.
 DFD Detection and Fire D
 Responded

ed at that realm. For example, a room fire occurs when all fuel
e room are involved with the flame. Once a room fire is establis
s properties are independent of the way the fire was initiated.

property of fire suggests the modeling approach used in which fire
opment is represented by realms and realm transition probabilities.

The variables of a realm are the time distribution of that realm
d probabilities of transition to other realms. For example, cons
alm/action combination 2DFD (as identified in Figure 2-4) which i
econd material involved, fire detected, and fire department respo
establishing that combination, it is claimed that once the realm
erred, the properties of that realm, i.e., the transition probabi
om the realm and the time the realm exists, are independent of pr
ous realm. It is also claimed that the next transition is indepe
the time spent in the realm. Thus, realm/action sequence 0-1D-2
FD leads to the same situation as sequences 0-1D-1DS-2DFD or 0-1D
FD. It is assumed that aggregating data from all sequences leadin
alm/action combination 2DFD is a reasonable way to compute the pr
es of that combination.

Combinations selected for modeling are believed to be reasonab
least for an initial effort. If it is found that transition pro

Parameter Conversion Logic

Parameter conversion logic translates building parameters into fire development and products of combustion parameters. In a sense, it translates the real world of building and living practices into a model of fire in a building. As suggested previously, the plan is to develop the logic from fire test data and theory, validated with fire department experience data. Where necessary, voids in the data will be overcome using professional judgement.

Since development of a data-based logic is to be completed during the Phase III portion of the project, an initial "cut" was provided using professional judgement. In order to provide a suitable format for judgement estimates of real time and transition probabilities, various combinations of the fire development realms and human actions were provided and estimators asked to identify suitable probability estimates. A handbook was formed providing instructions and data sheets for the estimators. The following sections are extracts from that handbook. Instead of enclosing blank data sheets, as was the case for the original handbook, completed data sheets for two sample fires - a kitchen fire (Tables 3-1a and 3-1b) and bedroom fire (Tables 3-2a

ble 2-2 where eight realms are identified. Realm 0 is the "no fire" situation and Realm 1 corresponds to the "first material involved." Since fire spread may be different for each type of fire, separate tables are used for each type of fire.

Tables 3-1 and 3-2 are provided in two parts, Section a and Section b. Section a is for presenting the probability of transition from one realm to another. Each fire realm is associated with a table row. For example, Realm 1, which corresponds to first material involved, is associated with the first row. There are eight columns associated with each row where one column per row has been crossed out, i.e., not to be used. The first column marked "0" is for the probability of transfer to Realm 0. Similarly, the element in the third column under "2" is to be used to enter the probability of transfer to Realm 2. The column under "1" is crossed out in row 0 because it has no physical meaning, in other words, a transition from no fire to fire cannot take place.

Section b of each table is for recording the mean time the fire will remain in the present-realm (represented by the row) before transitioning to each possible next-realm (represented by a column). If the probability of transfer from one realm to another (as recorded in

(represented by a row) To Other Realms (represented by each column)

Source of Heat 6.* Kitchen Stove

First Material Fabric

Location of Fire Initiation Kitchen

Realm

Human
"Realm"

		0	1	2	3	4	5	6	7
1	D	.70	X	.30					
2	D	.70	.25	X	.05				
3	D	.001			X	.99	.009		
4	D					X	.75	.24	.01
5	D						X	.30	.70
6	D							X	1.00
7	D	1.00							X
1	DS	.99	X	.01					
2	DS	.97	.029	X	.001				
3	DS	.02			X	.97	.01		
4	DS					X	.98	.01	.01
5	DS						X	.99	.01
6	DS							X	1.00
7	DS	1.00							X
1	DFD	.99	X	.01					
2	DFD	.97	.029	X	.001				
3	DFD	.95			X	.035	.01	.005	
4	DFD	.95				X	.04	.01	
5	DFD	.93					X	.06	.01
6	DFD	.80						X	.20
7	DFD	1.00							X

*Type fire defined in Table 1

Mean Time in Each Realm (represented by a row) Before

Transfer to Other Realms (represented by each column)

Source of Heat 6. Kitchen Stove

First Material Fabric

Location of Fire Initiation Kitchen

Human
"Realm"

	0	1	2	3	4	5	6	7
—								
D	.25		.75					
—								
D	2.00	2.00		8.00				
—								
D	20.00				8.00	9.00		
—								
D					7.00	8.00	2.00	
—								
D						2.00	10.00	
—								
D							10.00	
—								
D	Burnout							
DS	.25		.5					
DS	1.0			.25				
DS	10.00				7.00	7.00		
DS					10.00	12.00	2.00	
DS						10.00	10.00	
DS							5.00	
DS	Burnout							
DFD	3.00		3.5					
DFD	4.00	4.00		7.00				
DFD	5.00				6.00	8.00	7.00	
DFD	6.00				10.00	9.00		
DFD	10.00					12.00	17.00	
DFD	12.00						20.00	
DFD	30.00							

Time in minutes

Human
"Realm"

Source of Heat 9.* Cigarette
First Material Fabric
Location of Fire Initiation Bedroom

	0	1	2	3	4	5	6	7
—								
D	.80		.20					
—								
D	.40			.60				
—								
D	.30				.65	.05		
—								
D						.95	.05	
—								
D							.30	.70
—								
D								1.00
—								
D	1.00							
DS	.99		.01					
DS	.97	.029		.001				
DS	.02				.97	.01		
DS						.98	.01	.01
DS							.99	.01
DS								1.00
DS	1.00							
DFD	.99		.01					
DFD	.97	.029		.001				
DFD	.95				.035	.01	.005	
DFD	.95					.04	.01	
DFD	.93						.06	.01
DFD	.80							.20
DFD	1.00							

*Type fire defined in Table 1

Mean Time in Each Realm (represented by a row) Before

Transfer to Other Realms (represented by each column)

		Source of Heat <u>9. Cigarette</u>							
		First Material <u>Fabric</u>							
		Location of Fire Initiation <u>Bedroom</u>							
Human		0*	1	2*	3	4	5	6	7
"Realm"									
—									
D	5./20.	X	3./20.						
—									
D	5./25.		X	20.					
—									
D	20.			X	3.	7.			
—									
D					X	7.	8.		
—									
D						X	2.	10.	
—									
D							X	10.	
—									
D	Burnout							X	
DS	.25	X	.50						
DS	1.	.50	X	3.					
DS	10.			X	7.	7.			
DS					X	10.	12.	2.	
DS						X	10.	10.	
DS							X	5.	
DS	Burnout							X	
DFD	3.	X	3.5						
DFD	4.	4.	X	7.					
DFD	5.			X	6.	8.	7.		
DFD	6.				X	10.	9.		
DFD	10.					X	12.	12.	
DFD	12.						X	20.	
DFD	30.							X	

*Dual estimates relate to a flaming ignition/smoldering ignition.

The second row is filled out in a similar way except that now the entry under the column marked (2) is crossed out. The first set of rows (1-7) are associated with fires burning without detection (\bar{D}). The second set of rows (8-14) are associated with a fire that has been detected and suppression work initiated (DS). Since one or more individuals are engaged in suppression work, the probability of transition from the present realm to Realm 0 might be expected to increase and perhaps, the mean time the present-realm exists prior to transition may change.

Finally, the last seven rows (15-21) represent the fire situation where the fire has been detected and the fire department responded (DFD). Again, one might expect that the transition probabilities and mean realm existence times might be different once the fire department has responded. In each of the three cases identified above (\bar{D} , DS, DFD), the realm time of interest is the time the combination fire realm and human realm exists. Thus, we may find that the fire may be in Realm 1 undetected for awhile (\bar{D}), and then move to fire Realm 1 detected (DS), where the human is trying to suppress the fire. Fire suppression may continue for awhile followed by fire department response. In each case, the mean realm time of interest is the mean time each case exists. Thus, for example, the mean time the fire is in Realm 1 with detection and fire department response does not include time the fire was in Realm 1 with no detection and/or manual occupant suppression.

In summary, the two table sections (a and b) are to contain the probabilities of each transition (Section a) and the mean time in a realm before transition to another realm (Section b). Each possible

The Effect of Human Actions on Fire

Tables 3-3 and 3-4 are also provided in two parts, a and b. Each table records estimated detection/action probabilities and time for the human actions affecting the fire. Two tables are provided, one for each type of fire. Section a presents the probability of transition from each detection/action state to other detection/action states (DAS) as a function of the fire realm. Section b presents the mean existence time of the DAS prior to transfer to another DAS as a function of fire realm. For example, the first row of Section a presents two probabilities. One is the probability of transfer from the "no detection" to "detect-suppress" and the other is the probability of transfer from "no detection" to "detection and Fire Department response." The corresponding entries in Section b give the mean time the system will be in the "no detection" realm before transition to "detect and suppress" or "detection and fire department response."

Note that these entries should not reflect the length of time one expects a fire realm to exist. Instead, of concern here is the length of time the fire could develop undetected. For example, if fire detection is not expected to occur for an hour, but the fire will self extinguish after a half hour, the model will automatically "take care of" that set of events.

The second set of seven rows corresponds to the probability of transfer from "occupant fire suppression" to either "fire department response" or "occupant evacuation." Here we are interested in the probability that the individual will notify the fire department and the mean time that person will engage in fire suppression prior to either the fire de-

Probability of Transition from Each Fire and Human
 Realm Combination (represented by a row) to Other Human
 Realms (represented by each column)

Reference Fire # 6 of Table 2-1

		DS	DFD	E
1	\bar{D}	.96	.04	
2	\bar{D}	.92	.08	
3	\bar{D}	.25	.75	
4	\bar{D}	.05	.95	
5	\bar{D}	.01	.99	
6	\bar{D}		1.00	
7	\bar{D}		1.00	
1	DS		.50	.50
2	DS		"	"
3	DS		"	"
4	DS		"	"
5	DS		"	"
6	DS		"	"
7	DS		"	"

\bar{D} FIRE NOT DETECTED

DS FIRE DETECTED and fire
 suppression initiated

DFD FIRE DETECTED and fire
 department responded

E Evacuation

Table 3-3a

Mean Time in Each Fire and Human Realm Combination
(represented by a row) Before Transfer to Other Human Realms
(represented by each column)

Fire # 6 of Table 2-1

	DS	DFD	E
\bar{D}	.5	.5	
\bar{D}	1.0	1.0	
\bar{D}	.5	.5	
\bar{D}	.5	.5	
\bar{D}	.5	.5	
\bar{D}		.25	
\bar{D}		.25	
DS		2.	2.
DS		2.	2.
DS		.5	.5
DS		"	"
DS		"	"
DS		"	"
DS		"	"

\bar{D} FIRE NOT DETECTED
 DS FIRE DETECTED and fire suppression initiated
 DFD FIRE DETECTED and fire department responded
 E Evacuation

Table 3-3b

Probability of Transition from Each Fire and Human
 Realm Combination (represented by a row) to Other Human
 Realms (represented by each column)

Reference Fire # 9 of Table 2-1

		DS	DFD	E
1	\bar{D}	.96	.04	
2	\bar{D}	.92	.08	
3	\bar{D}	.25	.75	
4	\bar{D}	.05	.95	
5	\bar{D}	.01	.99	
6	\bar{D}		1.00	
7	\bar{D}		1.00	
1	DS		.50	.50
2	DS		"	"
3	DS		"	"
4	DS		"	"
5	DS		"	"
6	DS		"	"
7	DS		"	"

D FIRE NOT DETECTED

DS FIRE DETECTED and fire
 suppression initiated

DFD FIRE DETECTED and fire
 department responded

E Evacuation

Mean Time in Each Fire and Human Realm Combination
 (represented by a row) Before Transfer to Other Human Realms
 (represented by each column)

Reference Fire # 9 of Table 2-1

		DS	DFD	E
1	\bar{D}	8.	10.	
2	\bar{D}	4.	4.	
3	\bar{D}	.5	.5	
4	\bar{D}	.5	.5	
5	\bar{D}	.5	.5	
6	\bar{D}		.25	
7	\bar{D}		.25	
1	DS		2.	2.
2	DS		2.	2.
3	DS		.5	.5
4	DS		.5	.5
5	DS		.5	.5
6	DS		.5	.5
7	DS		.5	.5

D FIRE NOT DETECTED

DS FIRE DETECTED and fire
suppression initiated

DFD FIRE DETECTED and fire
department responded

E Evacuation

Table 3-4b

Human Response Parameters

This section presents tables for recording estimates of movement parameters for individuals not affecting the fire. Table 3-5 gives the four types of human mobility organized into two categories. Tables 3-6 and 3-7 provide a means for recording the probability of transition from one location to another and the mean time in each location prior to transition. Table 3-6 is used with human mobility Category 1 (people capable of self-preservation) for each of the seven fire realms. Table 3-7 is associated with human mobility category 2.

The first part of each table presents the probability of transition from the location indicated by the row to the location indicated by a column. The second part of the table presents mean time an individual is in the location indicated by the row prior to transitioning to the location indicated by a column. In actual use Tables 3-6 and 3-7 each consists of seven pages where each page would be associated with a particular human mobility category and a fire realm. Thus, Table 3-6 consists of the seven pages where each of the seven pages would correspond to one fire realm. For the sake of example only the first page of each table (corresponding to Realm 1) is shown here.

Category 1 People Capable of Self Preservation

- Awake, non-disabled children of school age and adults

Category 2 People Who Are Nonambulatory, Infantile, Senile, or Otherwise Incapable of Self Preservation

- Sleeping, non-disabled children of school age and adults
- Physically or mentally impaired (including drugged) children of school age and adults
- Elderly

Table 3-5 Mobility Categories of Individuals

Response Times and Transition

Probabilities for Humans Not Affecting Fire

Mobility Category 1

Fire Realm 1

Probability Of Transition From Location (indicated by row)
To Another Location (indicated by column)

Relative Location of Individual	1	2	3	4	5	6
1. Room of fire origin	.919	.01	.02	.001		.05
2. Floor of fire origin	.90	.04	.02	.02	.01	.01
3. Exit	.90			.02	.04	.04
4. Floor beyond	.06	.04	.10	.60	.10	.10
5. Other dwelling	.001				.999	
6. Outside dwelling	.001					.999

Mean Time* Individual Is in Location (indicated by row)
Before Transitioning to Another Location
(indicated by column)

Relative Location of Individual	1	2	3	4	5	6
1. Room of fire origin	10.	4.	4.			
2. Floor of fire origin	10.	10.	10.	10.	10.	10.
3. Exit	10.	10.	10.	10.	10.	10.
4. Floor Beyond	15.	15.	15.	15.	15.	15.
5. Other dwelling	5.				5.	
5. Outside dwelling	5.					5.

*Time in minutes

Response Times and Transition
Probabilities for Humans Not Affecting Fire

Mobility Category 2

Fire Realm 1

Probability Of Transition From Location (indicated by row)
To Another Location (indicated by column)

Relative Location of Individual	1	2	3	4	5	6
1. Room of fire origin	.95	.02	.01	.01	.005	.005
2. Floor of fire origin	.05	.93	.005	.005	.005	.005
3. Exit	.01		.96	.01	.01	.01
4. Floor beyond				.9998	.0001	.0001
5. Other dwelling					1.000	
6. Outside dwelling	.01					.99

Mean Time Individual Is in Location (indicated by row)
Before Transitioning to Another Location
(indicated by column)

Relative Location of Individual	1	2	3	4	5	6
1. Room of fire origin	X	5.	5.	5.	5.	5.
2. Floor of fire origin	15.	X	15.	15.	15.	15.
3. Exit	15.		X			
4. Floor beyond				X	10.	10.
5. Other dwelling					X	
6. Outside dwelling	10.					X

A Test of the BFM

A digital computer simulation implementing the fire development and human response models has been developed. In order to test the simulation, the fire dynamics and human response parameter values estimated for the hypothetical dwelling and individuals given in the previous section were input to the computer simulation. Initial fire conditions were set at Realm 1 with no detection (\bar{D}) of fire. One thousand fire developments were produced - each according to the probabilities indicated.

In addition, certain probabilities were modified and the simulation repeated to reveal the effect of the modified probabilities on fire development. This is called sensitivity analysis. Such analysis permits a determination of the relationship between a fire development parameter (and in turn a building parameter) and the properties of fire development.

Simulations were run for several types of fires and human mobility categories. Results of the simulations for fire type 6 (source of heat: kitchen stove; location of ignition: kitchen; first material ignited: fabric; Table 2-1) and human mobility category 1 (People Capable of Self Preservation, Table 3-5) are given in Figures 3-1 through 3-3.

Figure 3-1 provides the probability of being in each realm for each one minute time increment. Quarter minute intervals were used in the simulation with results averaged over a minute for the plots. Note that after one minute 11.4 percent of the fires remain in the Realm 1 category, the remaining fires have either self-extinguished or transferred to other realms. After 15 minutes, the probability of a fire type 6 being in Realm 1 is zero. Likewise the probability of being in Realm 2

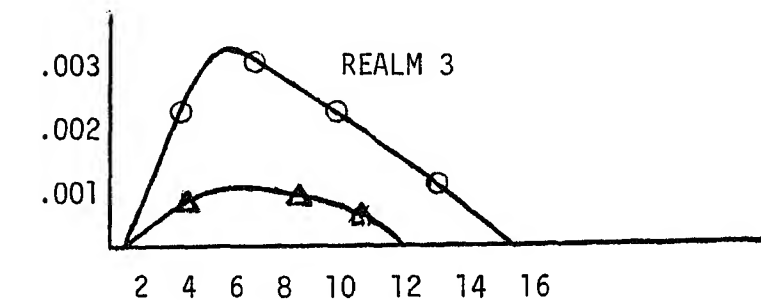
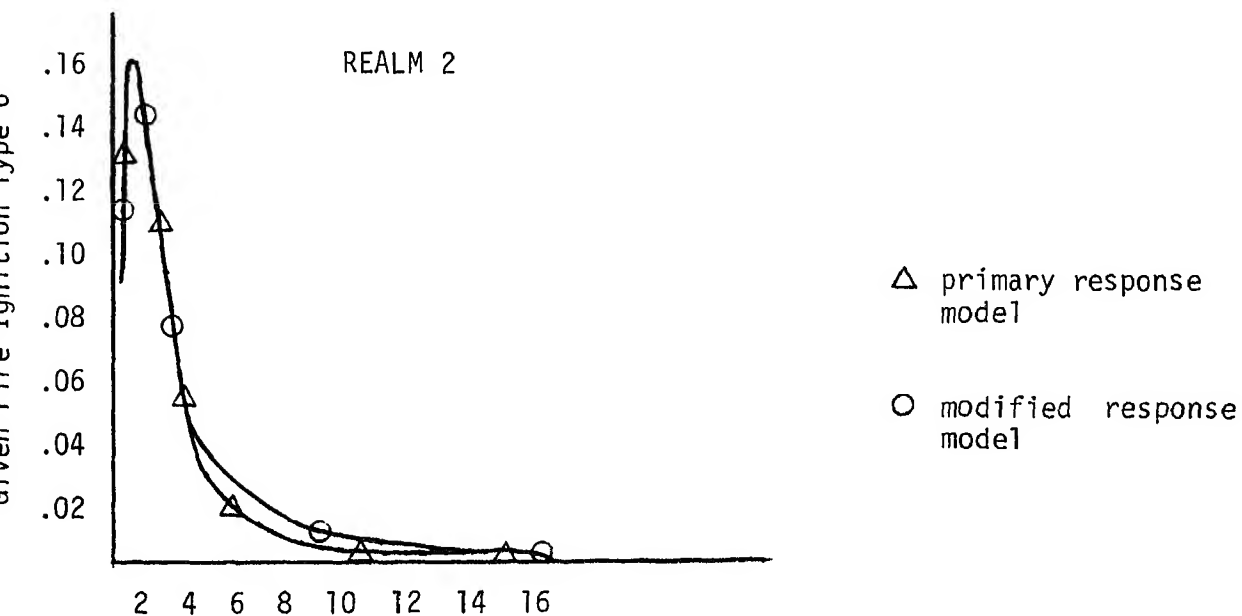
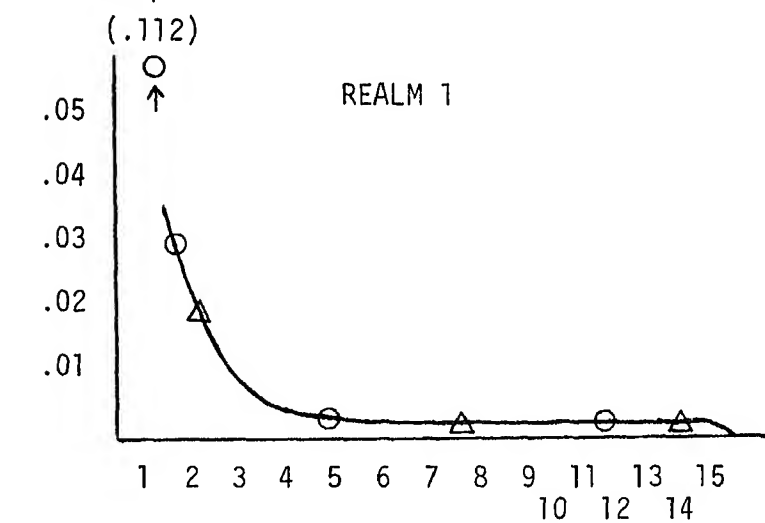
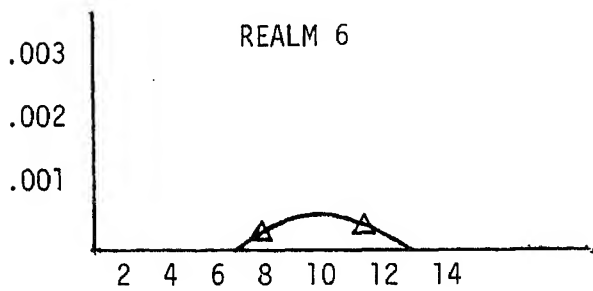
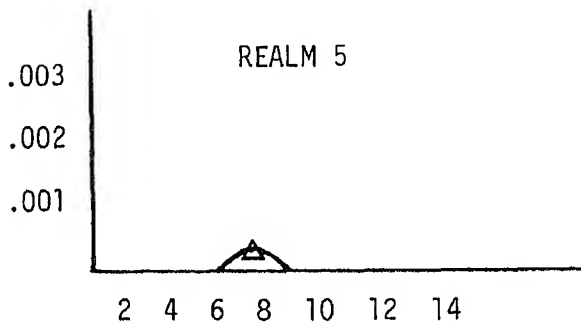
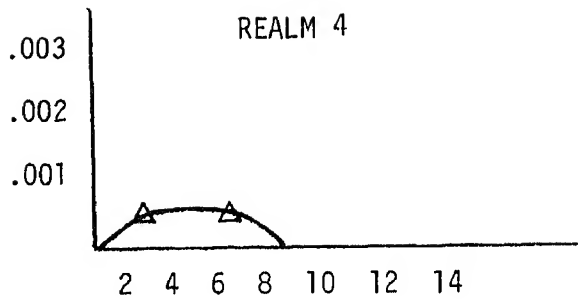


Figure 3-1a Realm/Time Distributions for



- \triangle primary response model
- \circ modified response model

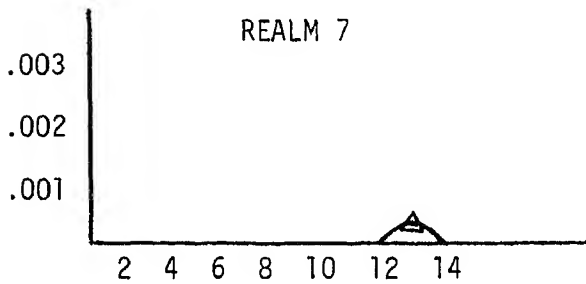
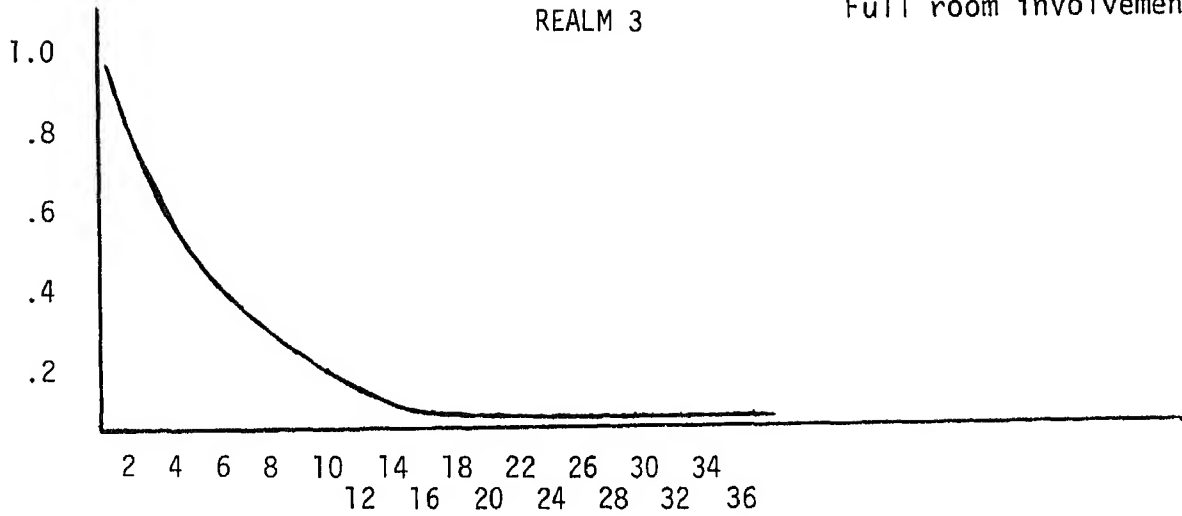


Figure 3-1a (continued)

Initial Condition

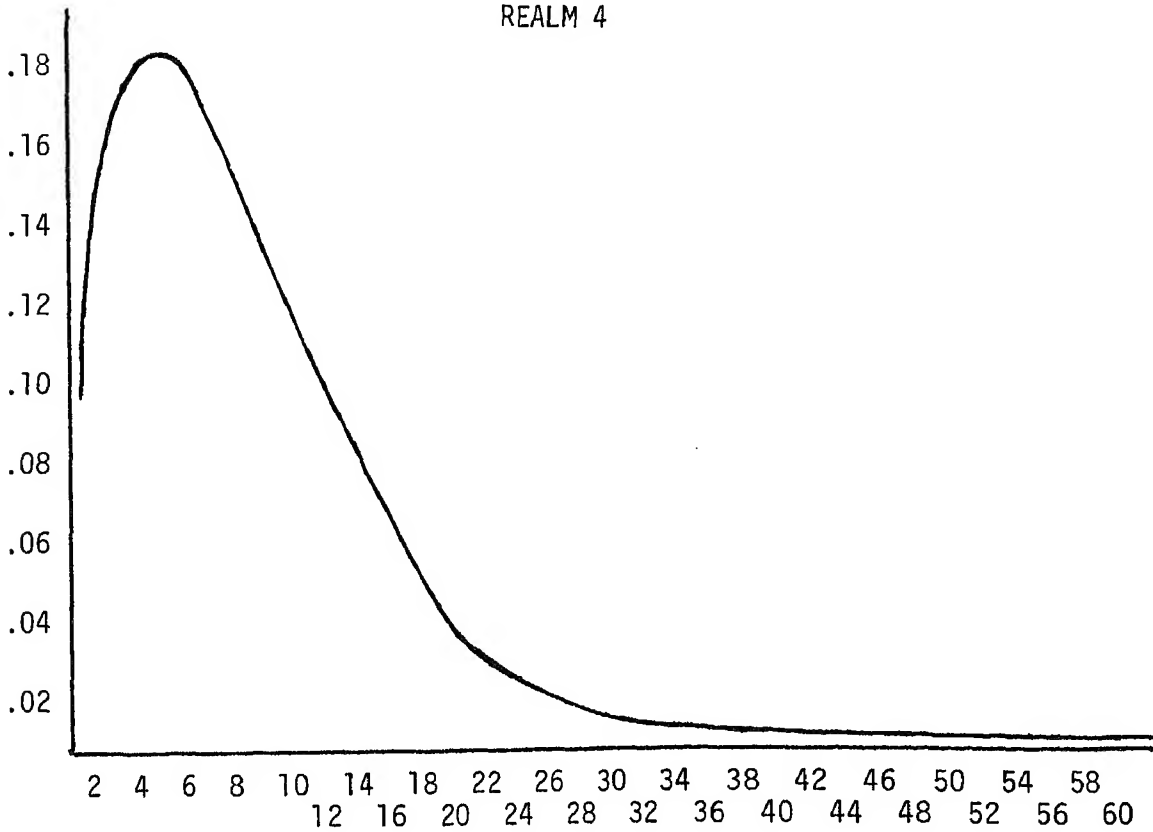
Full room involvement

REALM 3



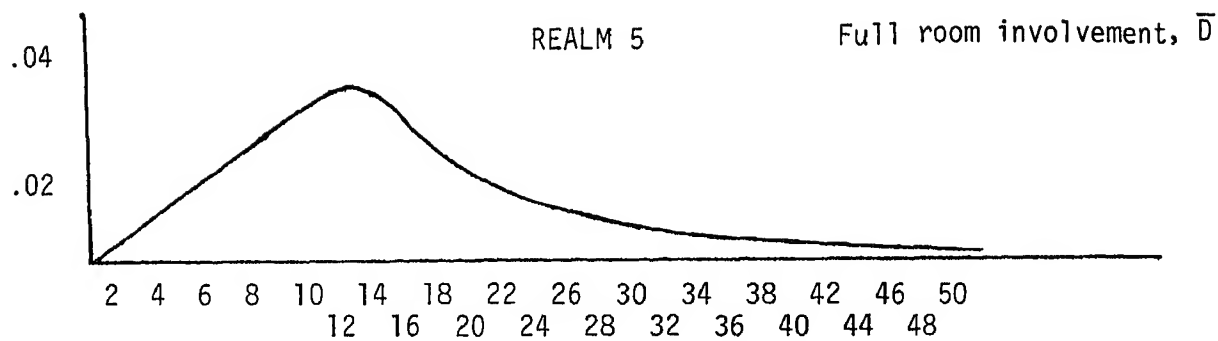
REALM 4

Probability of Being in Realm at Indicated Time Given Full Room Involvement (Realm 3)

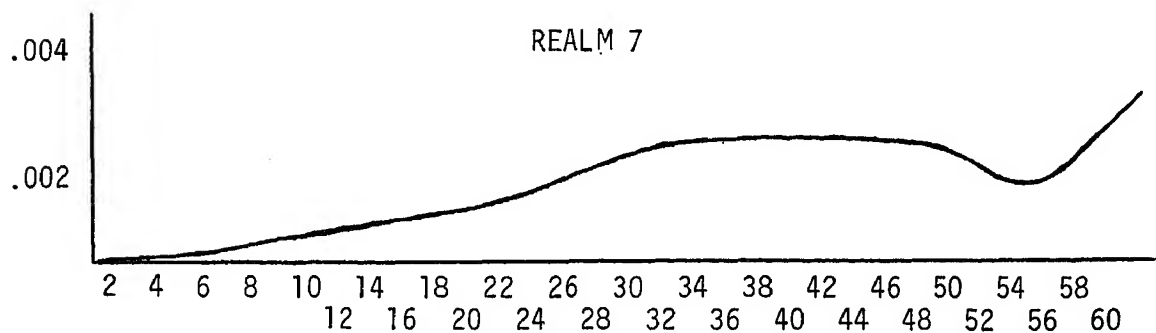
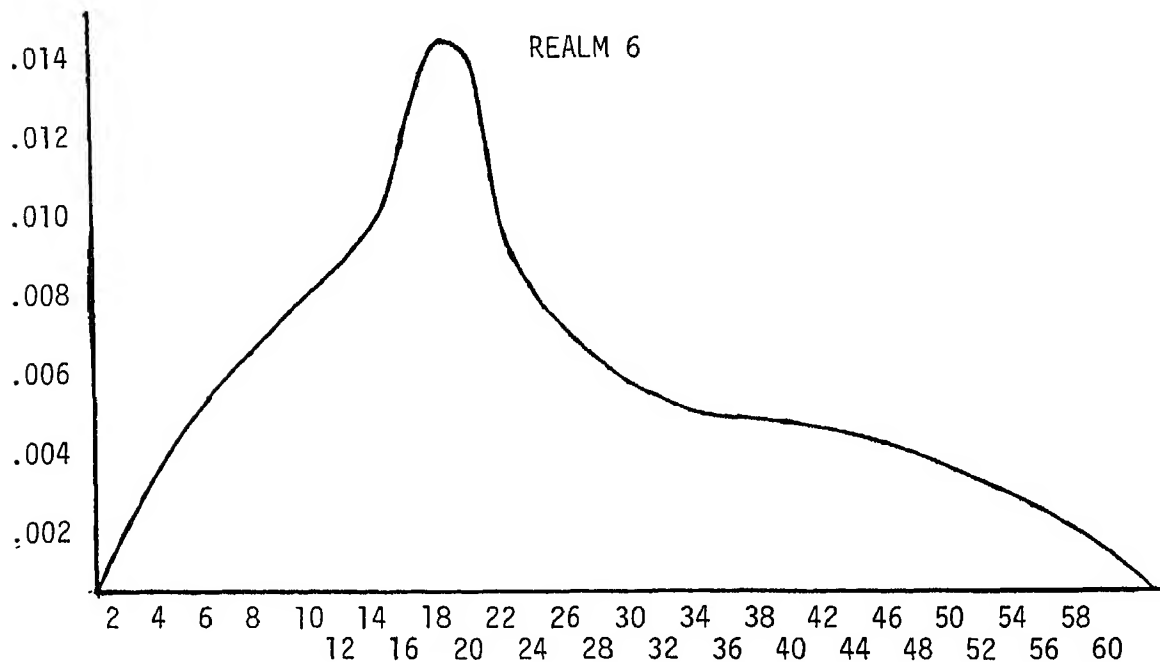


Time (min.) from start of Realm 3

Initial Condition



Probability of Being in Realm at Indicated Time Given Full Room Involvement (Realm 3)



Time (min.) from start of Realm 3

er 16 minutes is essentially zero. This is apparently due to suppression activity and an artifact of the simulation. (Note that the response of the primary model which corresponds to the data of Figure is shown by an " Δ ". An "0" is used to show the response of modified data to be explained subsequently.)

The simulation reveals that a probability of .00025 to .001 of being Realm 3 over the time interval 1 to 5 minutes. Probability limits less than .00025 are indicated as zero because the simulation used 10 runs with 4 intervals averaged over 1 minute. The .00025 limit provides a truncation of the distributions at 13 minutes for Realm 1, 14 minutes for Realm 2, and 12 minutes for Realm 3. If 10,000 runs were used, probabilities of .000025 could be indicated.

A practical way to extend the resolution of the simulation and permit investigation of the response of the remaining realms, is to use a two-phase simulation. First, fires are simulated starting at fire initiation. From this simulation, probability distributions are developed as well as other fire development properties. One property of interest is the probability (P_3) of reaching Realm 3. Secondly fires starting in Realm 3 are simulated. Fire distributions as shown in Figure 3-1 and 3-2 resulting from such a fire simulation must be weighted by P_3 .

The effect of the modified data, corresponding to a change in a fire detection/human response parameter, is illustrated by the modified response shown in Figure 3-1a. Probabilities for the primary and modified fire situation "Realm 1, DS" (fire Realm 1, detection and occupant suppression)

	Transfer to Realm 0	Transfer to Realm 2
Primary Model	.99	.01
Modified Model	.90	.10

An increase in the probability of transfer to Realm 2 greatly increases the probability that the fire will be in Realm 3. While the results presented are for a hypothetical dwelling and assumed realm time distributions (geometric distributions are assumed) are used, these results indicate how sensitivity analysis can be used to reveal the impact of building parameters and human responses.

Human response simulation provides the probability of the individual being in a specific location relative to the fire as a function of time since fire initiation. Figure 3-2 shows these probabilities. Of specific interest is the probability of the individual being in a location at a time when products of combustion are possibly injurious.

Figure 3-3 illustrates summary data for the fire development by providing the average time of fire as a function of fire detection/suppression activity.

The numerical results given here are offered to illustrate the type of data produced by the model. Data for all types of fires are not presented because of the volume and the hypothetical nature of the represented dwelling. The results were not just illustrative of the research program, however. Analysis of the data showed that:

- Realm times may be different depending on the next realm (a property affecting model design).

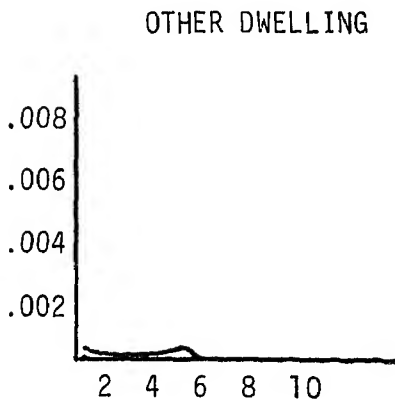
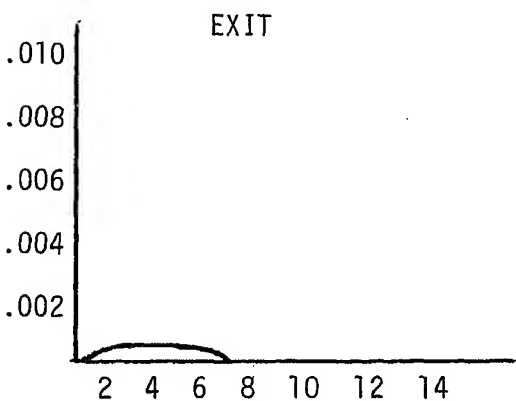
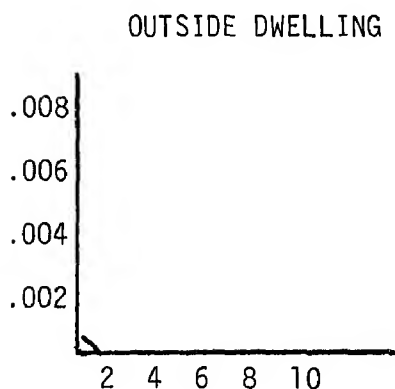
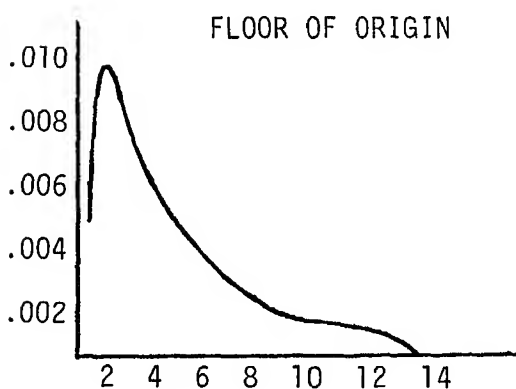
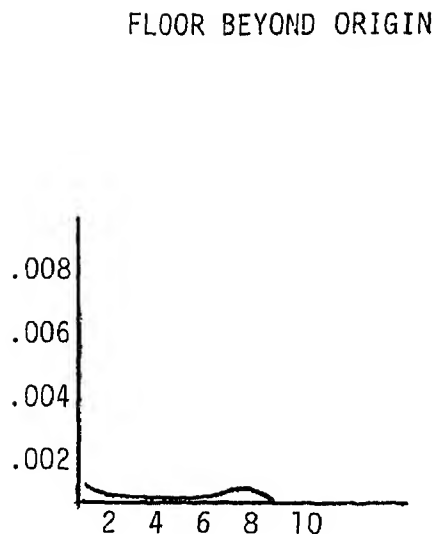
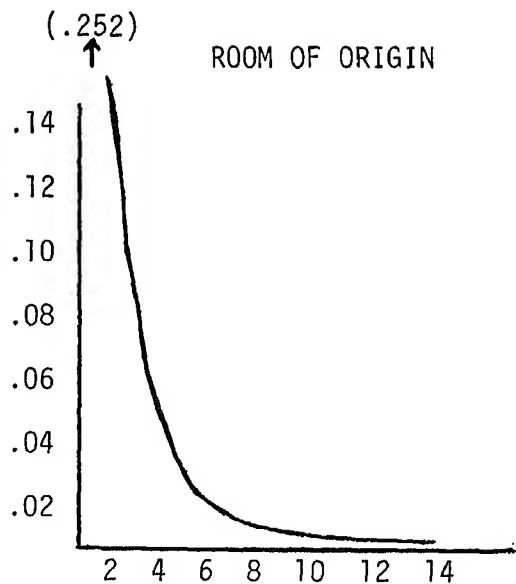
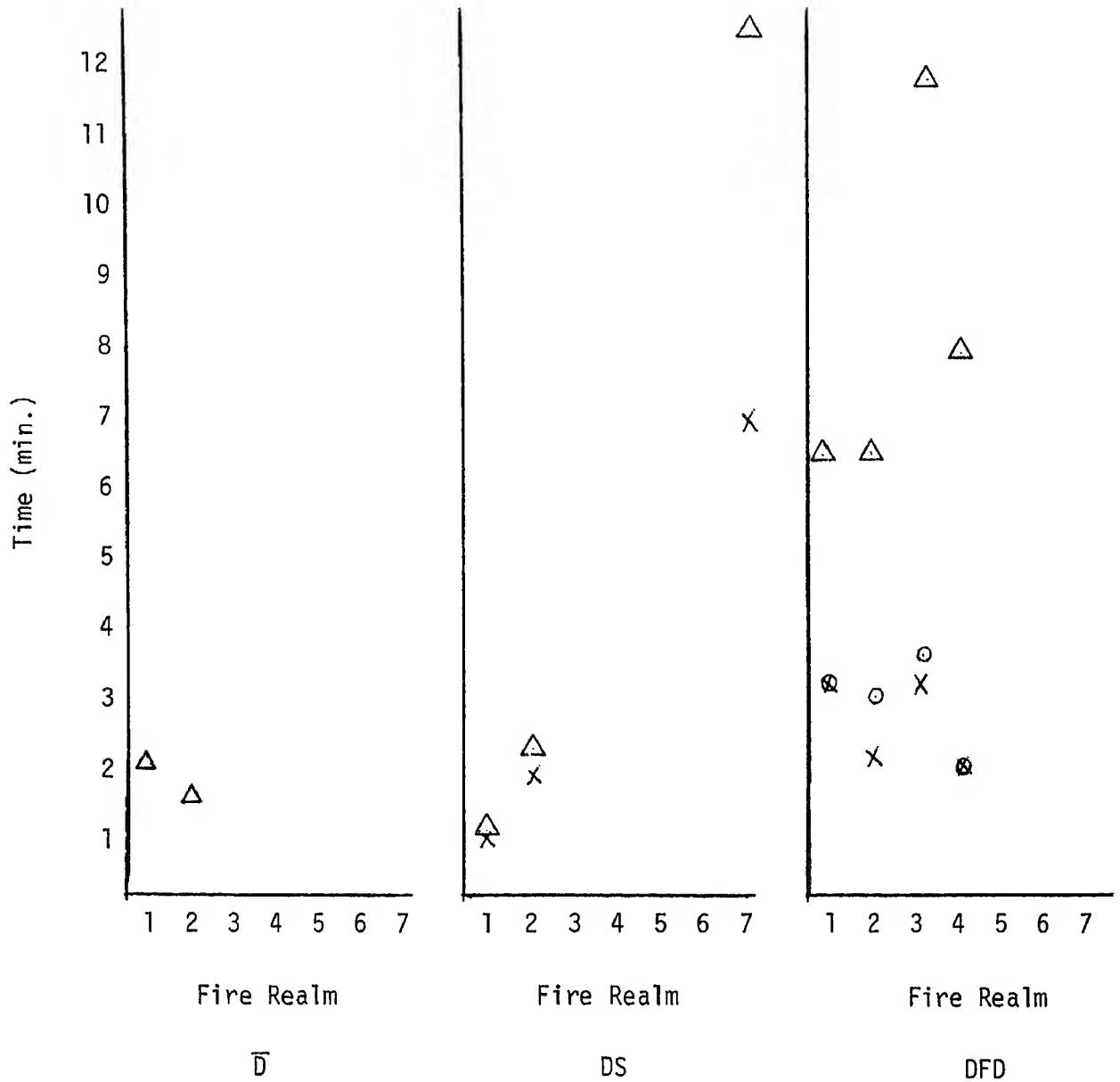


Figure 3-2 Location/Time Distribution for Hypothetical Individual Category 1

- △ Average Fire Length
- X Average Time Before Detection
- ⊙ Average Time Before Notification of Fire Department



- There is a need to explicitly represent the sequence of events resulting in the fire department arrival.
- There is a need for an investigation of the actual realm distributions.

Model Test: Effect on P_{FSOC} of Kitchen Wall Material

The digital computer program used to implement fire development and human response has been expanded to include building parameter conversion logic, products of combustion development, and firesafety objective competent Logic.

The program was developed by a modular method which enabled each section to be developed independently. A flow chart of two of the sections, POC spread and FSOC logic, is shown in Figure 3-4. The modular approach has an additional benefit. When new data or new analytical methods are developed, they may be included by changing only the appropriate modules and leaving the rest of the program untouched.

As a means of demonstrating the feasibility of the approach and also to test the expanded program, the BFM has been applied to a kitchen fire in a single-family dwelling. Various parameters, such as the effect of fire on POC development, had to be estimated because of lack of specific analytic data. These parameters were added to the program in a manner which allows easy modification in the future. The expanded digital program, variables used, and results are explained in the following paragraphs.

The Parameter Conversion Logic section of the BFM enables various fire parameters to be converted into a form useable to a digital computer program. Parameters are described in terms of changes to the original transition probabilities and mean times described in Tables 3-1 and 3-2. Using professional judgement, available data, and fire tests, it is possible to determine which transition probability(s) and mean time(s) will be af-

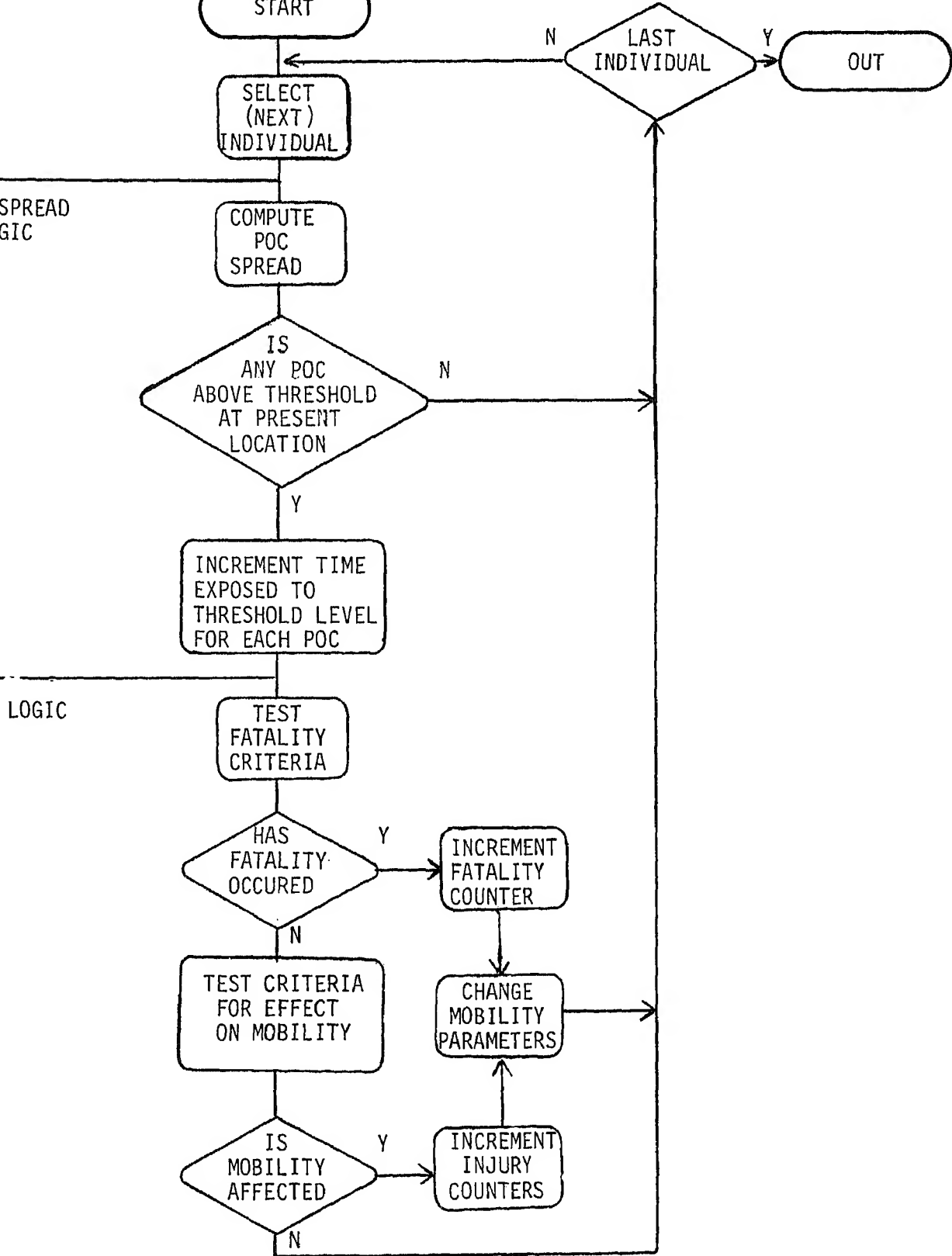


Figure 3-4. POC and ESOC Subroutines

form a data handbook. Parameter values presently in the handbook are those developed for the test application of a kitchen fire. The building characteristics considered for this fire are:

- all walls constructed with gypsum wall board (except for cabinets)
- one wall paneled (180 flame spread rating) and the other walls gypsum
- all walls paneled (180 flame spread rating)

Each parameter set has been evaluated to determine its effect on the probability of transitioning from Realm 2 (second material involved) with no human intervention to Realm 3 (full room involvement). A new mean time (in minutes) of remaining in that realm was also determined. These new values are shown in the figure below:

Parameter Set			
	1	2	3
new transition probability	.05	.10	.11
new mean time	8	6	5.5

These new values are tabulated and punched on computer cards. The digital computer program changes the fire transition table and mean time table to reflect these changes. The original values are in Tables 3-1 and 3-2.

One of the requirements of the fire transition table is that the sum of the probabilities in each realm transition row must add up to 1.0. To accomplish this the changed element of the row is set to the input

and the rest of the elements are multiplied by weighted correc-

value which forces the total of the row to be 1.0.

For example, in case 2 the new transition from Realm 2 to 3 is .10.

previous Realm 2 row is shown below:

	0	1	2	3	4	5	6	7
\bar{D}	.70	.25	X	.05	0.0	0.0	0.0	0.0

element under column 3 is changed to .10, and all other elements

multiplied by $(1.0 - .10)/(1.0 - .05) = .9474$. This gives the new

2 row shown below, which satisfies the original requirement, that

sum of the probabilities equals 1.0.

	0	1	2	3	4	5	6	7
\bar{D}	.66	.24	X	.10	0.0	0.0	0.0	0.0

Products of Combustion Model

This section of the BFM computes the severity of the POC according to the present fire realm. Three different levels of severity are distinguished. Level 1 is a slight hazard, such as low temperature and low concentrations of carbon monoxide (CO), level 2 is a medium hazard, and level 3 is a severe hazard. A table relating each POC used in this example (CO and temperature) to the associated hazard of each fire realm is shown in Table 3-8.

The POC model also tabulates the total amount of time an individual is exposed to each level of CO and temperature hazard. To do this, it is necessary to know which fire realms can potentially effect each location (Table 3-9). For example, if a person is outside the dwelling, that person will not be affected by the fire. However, if the person is on the floor of fire origin, that individual will be affected when the fire reaches the second room. When any effect of the fire occurs, the total time of exposure to the products of combustion increases. These times are used in the FSOC logic portion of the BFM to determine the extent of human injury.

Fire Realm	Products of Combustion	
	Carbon Monoxide	Temperature
First Material Involved	1*	1
Second Material Involved	2	1
Room of Origin Fully Involved	2	2
Second Room Involved	3	2
Floor of Origin Fully Involved	3	2
Floor Beyond Involved	3	3
Wellington Fully Involved	3	3

1 = slight hazard

2 = medium hazard

3 = severe hazard

HUMAN LOCATION	FIRE REALM
Room of fire origin	First material involved Second material involved Room of origin fully involved
Floor of fire origin	Second room involved Floor of origin fully involved
Exit	Full floor Floor beyond
Floor beyond	Floor beyond involved Dwelling fully involved
Other dwelling	None
Outside dwelling	None

Logic Model

The effect of exposure to different levels of products of combustion varies with the total time exposed. The FSOC which is being studied in this test case is the probability of a fatality. A fatality occurs at each of the three levels of hazard for both CO and temperature, depending on the total time exposed. Exposure to temperature level 3 for .30 min. can cause a fatality, as well as exposure level 2 for 10 min., and level 1 for 1 hour. The same is true for CO. A complete table is shown in Table 3-10.

There are two possible mobility impairments other than a fatality. There are slight and severe impairment, which correspond to slight and serious injury. The serious injury is tabulated as an injury even though in the future it could lead to edema and death. The different effect on mobility is caused by the different exposure times to each level of hazard (Table 3-10). These effects on mobility lead to changes in the probability of the people staying in their present location. The new probabilities are:

slight impairment = .25 probability of staying

severe impairment = .50 probability of staying

fatality = 1.00 probability of staying

CARBON MONOXIDE

Hazard Level	Mobility Impairment		
	Slight	Severe	Fatal
1	10.0 min.	20.0	30.0
2	.60	2.0	5.0
3	.30*	0.30	0.30

TEMPERATURE

Hazard Level	Mobility Impairment		
	Slight	Severe	Fatal
1	10.0 min	30.0	60.0
2	2.0	5.0	10.0
3	0.30	0.30	0.30

*In the model 0.30 is the smallest time interval. It is as close to instantaneous as is possible to input to the model.

Results of the Test

The purpose of the model is to evaluate the effectiveness of changes in building parameters with respect to fire safety. In this example, we have altered a particular building characteristic, kitchen exterior wall finishes. The fact that the model output shows differences in fire development consistent with the changed parameters indicates that the model developed in this report produces at least logical-consistent results.

When the fire development was simulated using the new probabilities, mean times caused by the changes in wall finish described previously, several observations were made: First, the fire developed more rapidly and had a greater likelihood of being severe (Figure 3-5). Second, the probability of injury increased as the finish materials became less flame retardant. Finally, the probability of a fatality remained the same (Table 3-11); at least for the computer runs conducted.

With an increased flame spread rating, it would be expected that the fire would be more likely to develop rapidly and with greater severity. The rapid development of this new fire explains the increase in the probability of injury. As the fire advances, the occupants are not able to escape quickly enough and will be injured in the process. However, the fact that the likelihood of death is not increased by the increased fire spread rates indicates that the changes in mean times and transition probabilities used in the example were not significant enough to prevent occupants in the room of origin from escaping death for these test

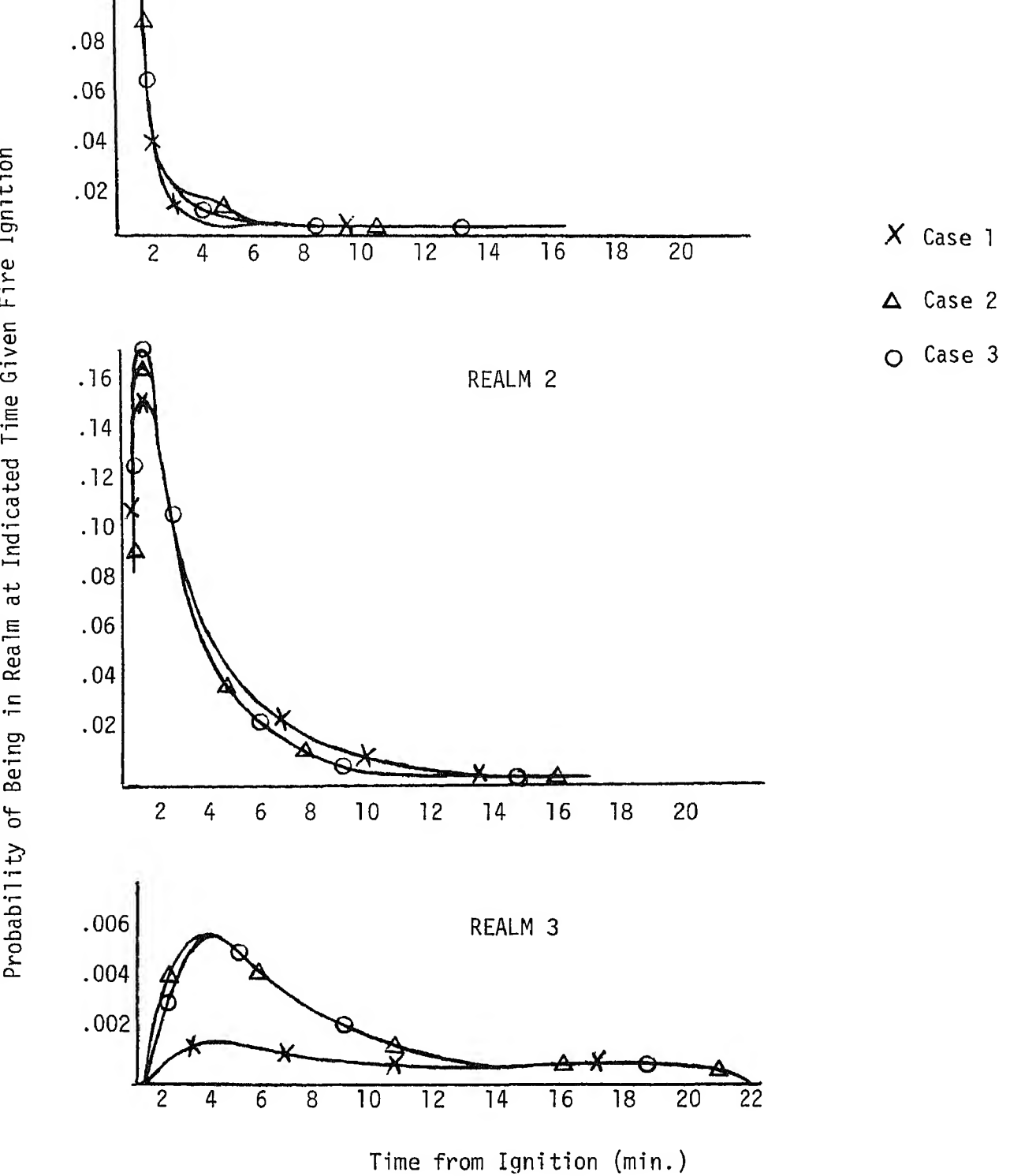
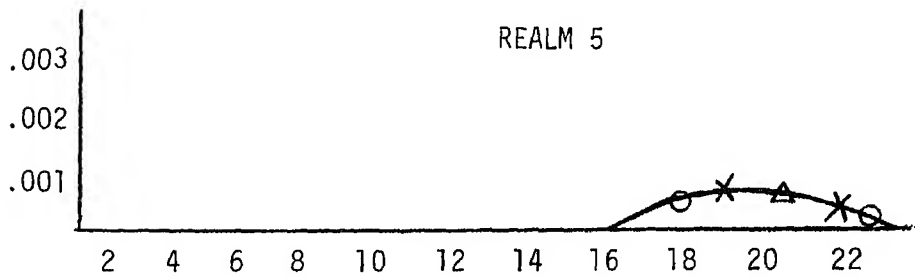
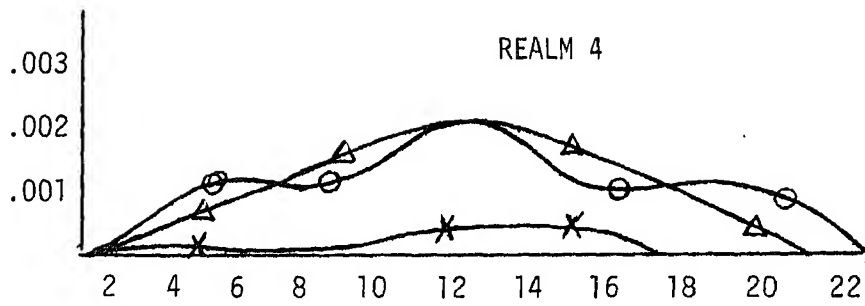


Figure 3-5 Realm/Time Distributions for Each Type of Kitchen Wall Covering



Time from Ignition (min.)

X Case 1

Δ Case 2

O Case 3

Figure 3-5 (continued)

Type of Injury Case*	Slight	Serious	Fatal	Total
1	.090	.160	.023	.273
2	.099	.160	.023	.282
3	.100	.162	.023	.285

*Cases are as described on page 64

Table 3-11 Probability of Injury and Fatality for Each
Type of Kitchen Wall Finish

CHAPTER IV

SUMMARY OF RESULTS AND PLANNED MODEL REFINEMENTS

Summary of Results

The Building Firesafety Model (BFM) is a tool that simulates the dynamics and interaction of the major fire factors from ignition to extinguishment. Fire factors are categorized in the BFM components as follows:

- Parameter Conversion Logic (PCL)
- Fire Development Model (FDM)
- Human Response Model (HRM)
- Products of Combustion Model (POCM)
- Firesafety Objective Component Logic (FSOCL)

Models have been constructed, programmed for a digital computer, and tested. In some cases portions of the BFM were constructed in a simplified manner to permit testing of the modeling concept. PCL, which converts fire development parameters from building parameters, was used and fire development parameters (real time and transition probabilities) estimated directly. Similarly, simplified POC and FSOCL models were used. The HRM included only the movement of people in emergency situations, and the effect of detection and suppression activity on fire spread.

Data for model construction and test are based on published literature and on the judgement of professional fire protection engineers. With this data, fire in kitchens with different wall finishes was compared.

FSOC probabilities for the cases studied, and established the feasibility of the approach used for the BFM.

Planned Model Refinements

Future work on the BFM will incorporate additional features that were purposely omitted in the initial model so that this model may be extended for application to additional types of dwellings and to develop general application techniques for the user. Additional features to be incorporated are:

1. Generation and propagation of smoke and other products of combustion
2. Refinement of the HRM to include other effects of human actions on fire development
3. Effects of structural and barrier failure on fire development
4. Effects of POC on an individual's mobility
5. Extension of the FSOC criteria to incorporate data on injury, fatality, structural damage, and mission

The BFM will be modified to represent fire development in other types of housing: multifamily, care-type, and mobile homes. Extension of the model to the multifamily case will involve consideration of structural integrity, compartmentation, sprinkler protection, and detectors. Models for care-type housing will include consideration of sprinklers, detectors, compartmentation, and special classes of human behavior. Mobile homes will require more changes in the models than the other cases, since this is a more complex fire problem. Construction practices unique to mobile homes require special consideration of geometry, ventilation, and exits, etc.

be in a form that is useful to builders, designers, code writers and approval authorities. Quantified parameters (e.g., room size, fuel load, flame spread rates) will be the inputs to the BFM. These inputs will be converted via the PCL to fire development parameters. This conversion is accomplished by altering the appropriate FDM transition probabilities.

According to the present plan, the output of the BFM will take two forms. One form consists of a computer printout revealing P_{FSOC} for a new or unique building design. The other form is an application guide for more conventional designs. The application guide will consist of graphs and tables showing the P_{FSOC} as a function of building parameter

Since the BFM must always represent current knowledge of fire and its effects, its design must allow for constant updating. To accomplish this the BFM and its computer program have been designed in modular form.

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APPENDIX A

MODELING OF THE
TIME-VARYING TRANSITION PROBABILITIES
OF FIRE REALMS

Introduction

One way to model fire spread is to define fire states (realms) and represent fire spread by probabilities of transition from one realm to another. This approach is based on the fact that flame properties are largely determined by the fuel and oxygen immediately available, and are not greatly influenced by previous events such as the type of ignition. As a result, a fire realm can be defined by an existing condition, not by a sequence of conditions. This property, whereby the process is defined by the present state (realm) and not by previous realms, permits modeling of the fire spread process by fixed probabilities of transition from one realm to another. A feature of this approach is that the process, as modeled, is a Markov process for which a great amount of mathematical theory is available.

Another property of fires which must be modeled is the fact that the length of time a fire burns in a given realm affects future fire spread. For example, the probability of a wall burn-through from a room fire increases with fire severity. This property may appear to negate fire spread modeling with a Markov process since the transition probabilities may vary with realm severity. However, each realm can be subdivided into sub-realms, as necessary, where each sub-realm represents fixed realm time, and fixed transition probabilities can be associated with each sub-realm. Furthermore, the number of sub-realms

roach

A state is considered absorbing if a process will never leave once it enters. Consider a Markov process with one transient state and one absorbing state as shown in Figure A-1.

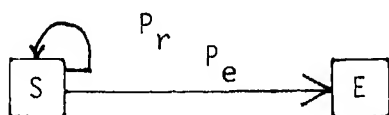


Figure A-1 Simple Markov Process

Let the outcome event be the entrance into the absorbing state. Then the probability $P_r(n)$ of entering E in exactly n time intervals, assuming each transition takes up one time interval, is the probability of remaining in state S for $n-1$ time intervals which occurs with probability P_r^{n-1} , times the probability of transition to the absorbing state on the next interval which occurs with probability P_e . Thus,

$$P_r(n) = P_r^{n-1} P_e$$

ere

$$P_r + P_e = 1 \quad (1)$$

A more general Markov process may be constructed by defining each state S_i to be the event that the outcome takes at least i units of time. One system for such a process is shown in Figure A-2.

This model is more powerful than the previous one in that the outcome achieved by entering an absorbing state is accomplished by

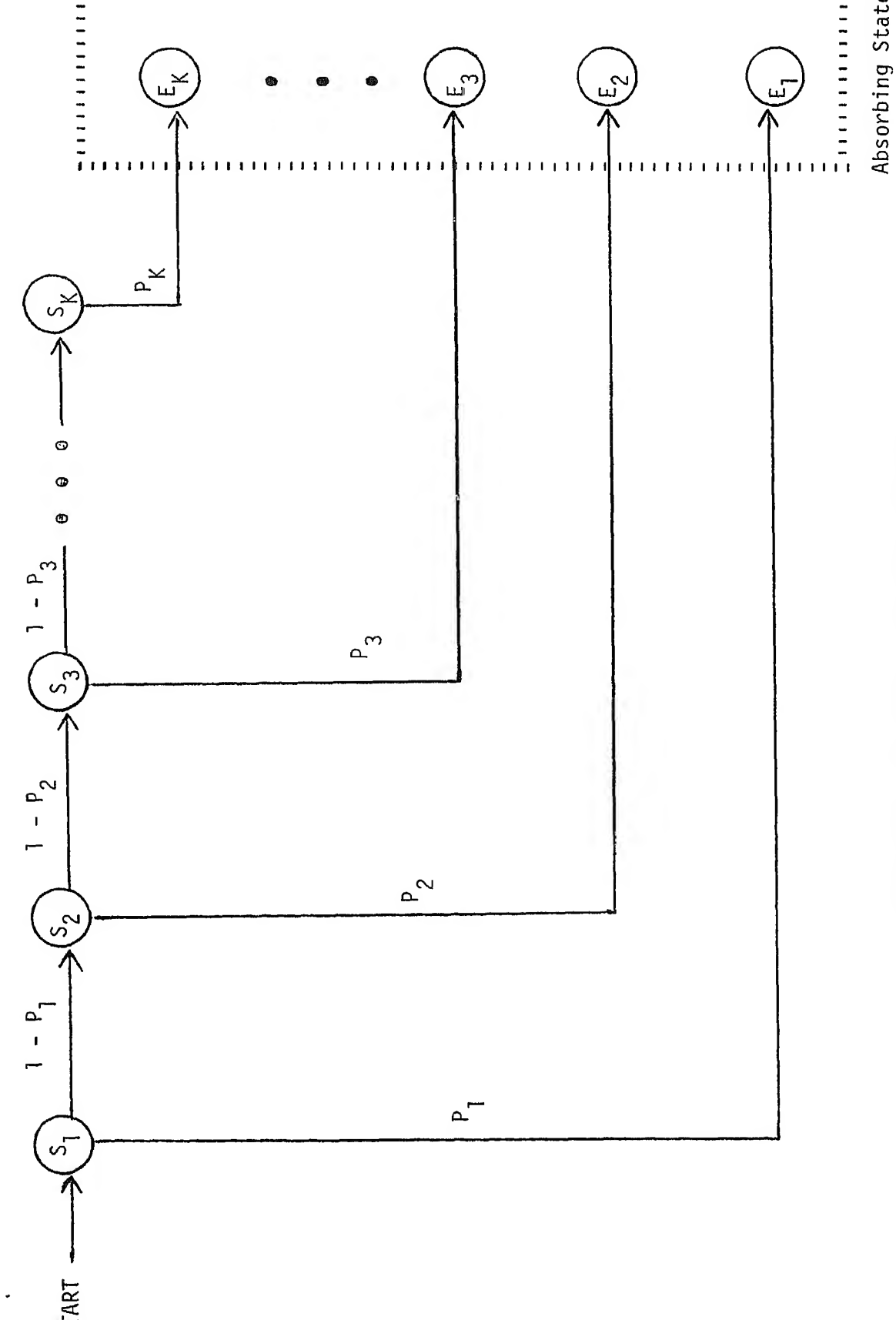


Figure A-2 A General Time Delay Process

This process model can be used to represent the existence of a realm with an arbitrary time distribution. The realm "existence" starts when the process moves to the sub-realm (state) S_1 . It terminates when the process moves to one of the absorbing states (E_1, E_2, \dots, E_k). If the process terminates in exactly one interval, it exists via state E_1 . Likewise if the process terminates in exactly i intervals, it exits via state E_i . Since the exit state is a unique function of the number of intervals, transition probabilities from the sub-realm can be assigned to each absorbing state E_i . Thus fixed transition probabilities which reflect the desired function of time can be assigned to each absorbing state E_i . This allows different transition probabilities, which can be assigned without restriction, to be associated with each process time interval.

In the above discussion, states E_i are treated as absorbing with respect to the other sub-realm states S_i . This is to facilitate calculations; however, states E_i are actually entry points to the subsequent realms.

The probability distribution for entering any absorbing state for the general Markov process may be obtained by constructing the transition matrix (Z) as shown in Figure A-3. In the transition matrix, all absorbing states are combined into state (E) to facilitate calculation of transition probabilities for specified time distributions. Each matrix entry a_{ij} denotes the probability of process transfer from the state assigned to row i to the state

	E	S_1	S_2	S_3	•	•	•	S_K	
E	1	0	0	0	0	0	0	0	• • •
S_1	P_1	0	$1-P_1$	0	0	0	0		
S_2	P_2	0	0	$1-P_2$	0	0	0		
S_3	P_3	0	0	0	$1-P_3$				
•									
•									
•								$1-P_{K-1}$	
S_K	P_K								
		•	•	•					

$$= \left[\begin{array}{c|c} 1 & 0 \\ \hline R & Q \end{array} \right]$$

Let Π_0 be a column vector where element b_i denotes the initial probability of being in the state assigned to row i . Since the process is always started in state S_j , it follows that Π_0 is

$$\Pi_0 = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

Let Π_n be the probability vector of being in each state in n time intervals. Then it follows from the definitions of Z and Π_0 that

$$\Pi_n = Z^{T(n-1)}\Pi_0 = \begin{bmatrix} 1 & R^T \begin{bmatrix} n \\ \sum_{i=1}^n (Q^T)^i \end{bmatrix} \\ 0 & (Q^T)^n \end{bmatrix} \times \begin{bmatrix} 0 \\ 1 \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (2)$$

where Z^T , R^T , and Q^T are transpose matrices.

Thus element 1 of Π_n denotes the cumulative probability $F(n)$ of entering any absorbing state. Thus it follows that the probability $f(n)$ of entering an absorbing state in exactly n time intervals is:

$$\begin{aligned} f(n) &= F(n) - F(n-1) = \text{element 1 of } (\Pi_0 - \Pi_{n-1}) \\ &= \text{element 1 of } \left[R^T \begin{pmatrix} n \\ \sum_{i=1}^n Q^T i \end{pmatrix} - R^T \begin{pmatrix} n-1 \\ \sum_{i=1}^{n-1} Q^T i \end{pmatrix} \right] \\ &= \text{element 1 of } \begin{bmatrix} R^T & Q^{nT} \end{bmatrix} = \text{element 1 of } (Q^n R) \\ &= P_n (1-P_{n-1}) (1-P_{n-2}) \dots (1-P_1) = P_n \prod_{i=1}^{n-1} (1-P_i) \end{aligned}$$

In applications where the desired time distribution is known, it can be sampled at equal intervals to yield $f(i)$, $i = 1, \dots, n$. Then the transition probabilities (P_k) are calculated from

$$\begin{aligned}
 P_1 &= f(1) \\
 P_2 &= f(2)/(1 - P_1) \\
 &\cdot \\
 &\cdot \\
 &\cdot \\
 P_k &= \left(f(k) / \prod_{i=1}^{k-1} (1 - P_i) \right) = \frac{f(k)}{f(k-1)} \left(\frac{P_{k-1}}{1 - P_{k-1}} \right)
 \end{aligned} \tag{3}$$

The corresponding process shown in Figure A-2 has the probability distribution determined by the $f(i)$.

The various $f(i)$ are determined by sampling a given time distribution. As the width of the sampling interval (and thus the unit of time in the Markov process) is made smaller, the set of $\{f(i): i = 1, \dots, n\}$ will approximate the distribution more accurately.

Example: Model for a realm with normally distributed time

As an example, consider a realm with an existence time which is normally distributed (mean of 3.4 and a variance of 1) as shown in Table A-1. A sampling time interval of 0.68 is used. The probabilities $f(n)$ are the probabilities the realm will exist for exactly n intervals. The transition probabilities P_i are obtained using Equation 3. The resulting process is shown in Figure A-4.

TIME DELAY	n	$f(n)$	P_n
$(-\infty, 0.68)$	1	0.0033	0.0033
$(0.68, 1.36)$	2	0.0174	0.0175
$(1.36, 2.04)$	3	0.0662	0.0676
$(2.04, 2.72)$	4	0.1614	0.1768
$(2.72, 3.40)$	5	0.2517	0.3348
$(3.40, 4.08)$	6	0.2517	0.5034
$(4.08, 4.76)$	7	0.1614	0.6500
$(4.76, 5.44)$	8	0.0662	0.7618
$(5.44, 6.12)$	9	0.0174	0.8406
$(6.12, \infty)$	10	0.0033	1.0000

Mean = 3.4

Variance = 1.0

Sampling time = 0.68

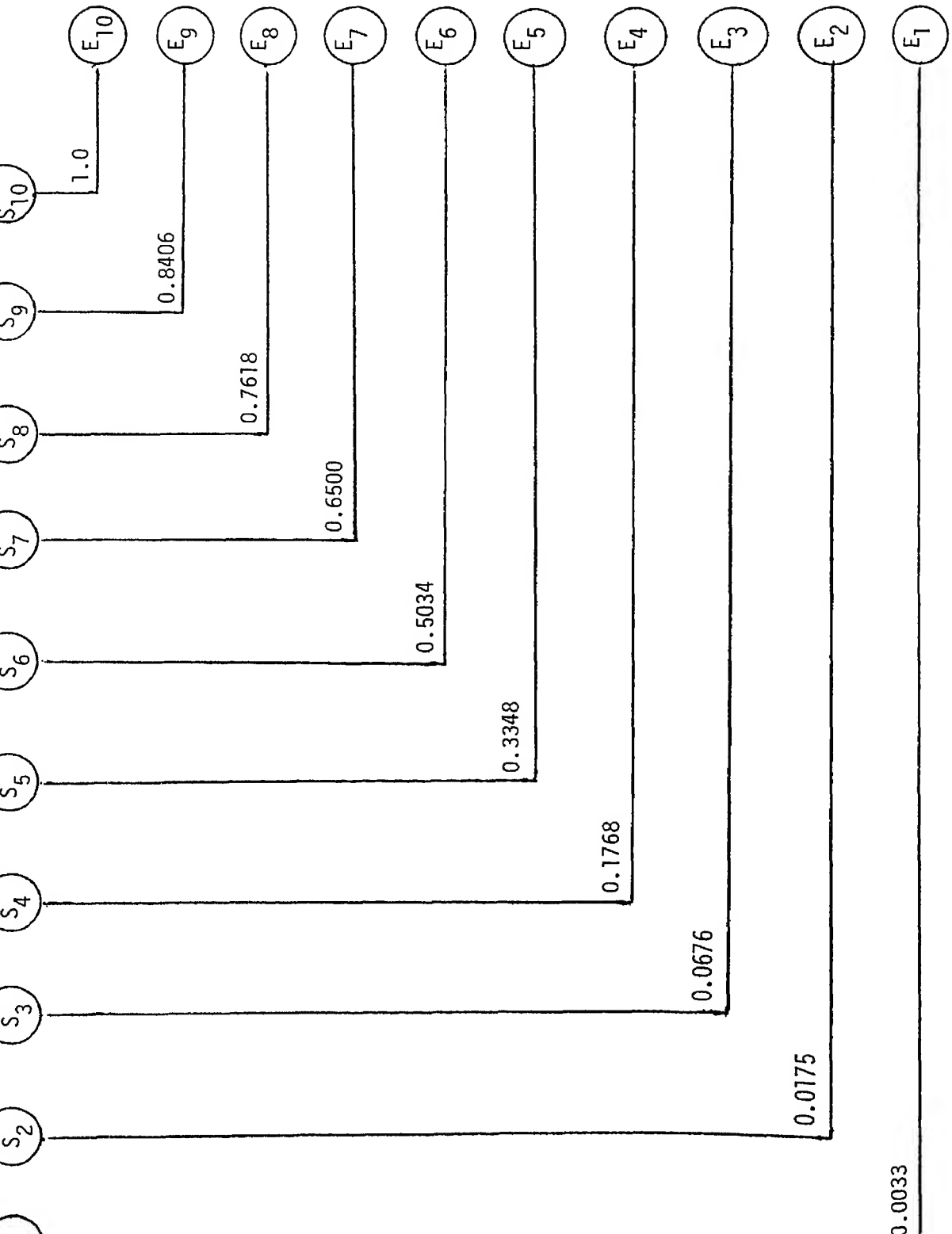
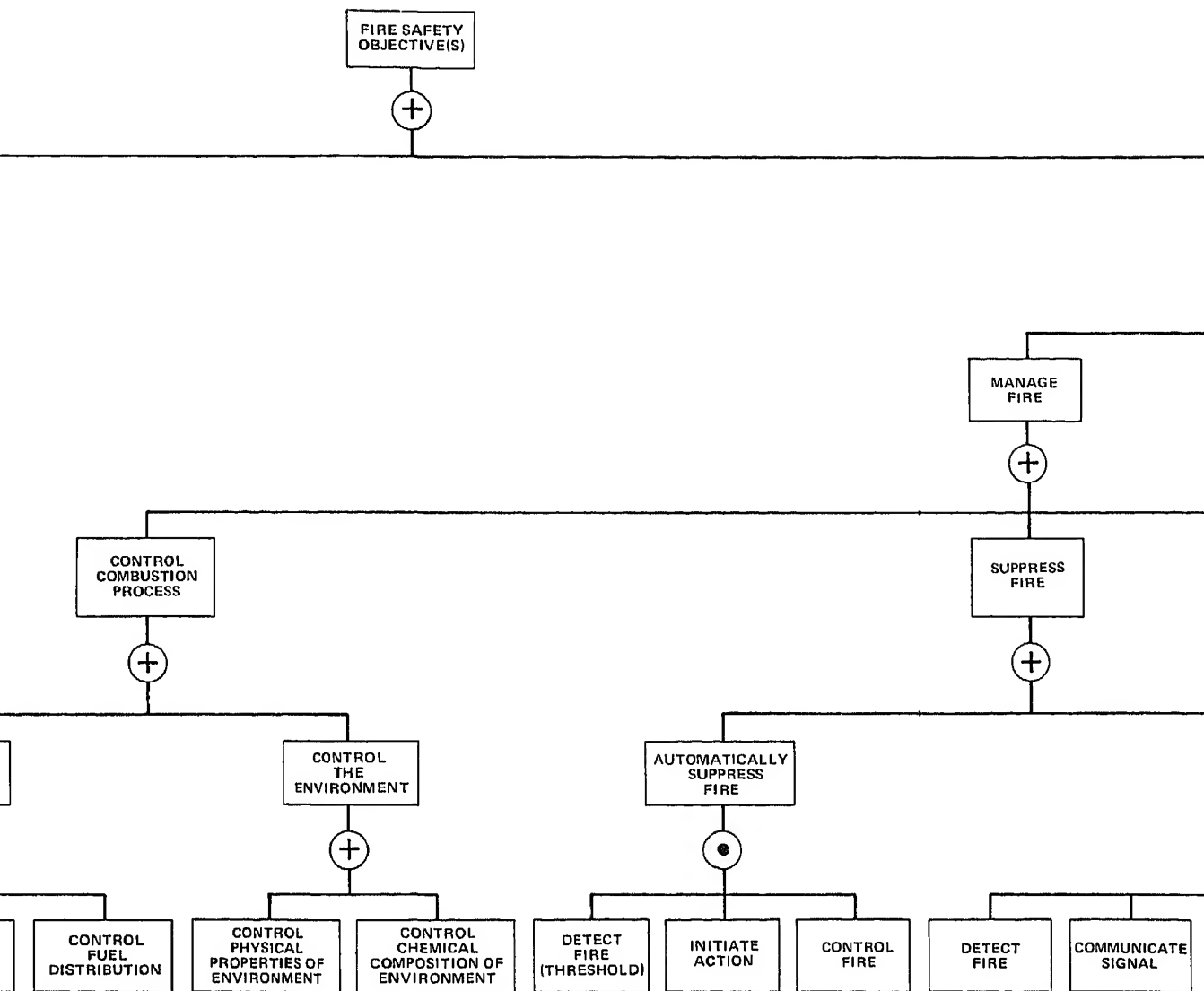


Figure A-4 Process Model for a Normal Distribution

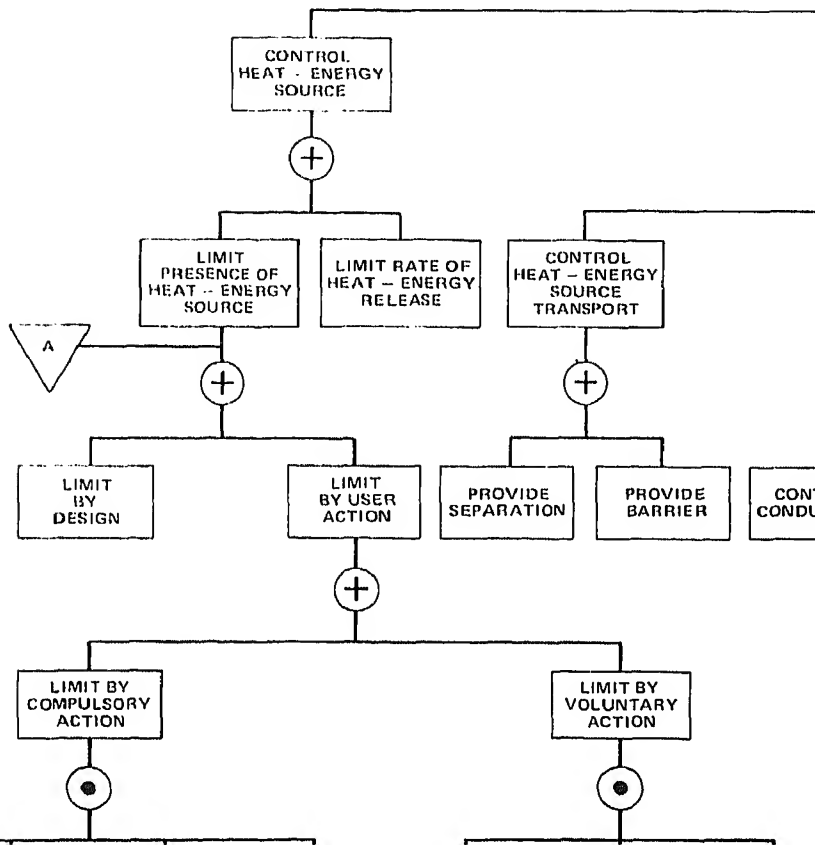
APPENDIX B

DECISION TREE



DECISION TREE

Committee on Systems Concepts
for Fire Protection in Structures
November 1974



APPENDIX C

DISCUSSION OF INITIAL RESEARCH AREAS

DISCUSSION OF INITIAL RESEARCH AREAS

This section describes the major areas that were researched during the development of Building Firesafety Model. It is hoped that researchers doing similar work may be able to use the material presented here in order to prevent duplication of effort.

THE INVESTIGATIVE PROCESS

Literature Search and Review

A literature search and review conducted through the NFPA technical library was an initial research task. Combinations of key words in context (KWIC) were used in the search. The number of abstracts retrieved from each combination are included in Table C-1. Totals reflect net documents after elimination of duplicates.

In addition to a computerized literature search, considerable manual search, including extensive review of NFPA library and staff-held documents, was conducted. Through extensive screening, duplicates and irrelevant items were eliminated and new documents added as they were identified and reviewed to form the Literature List in Appendix D.

One purpose of the literature search was to determine what research was underway and what research had been completed in the fire area that might assist in formulating the technical approach to this project. Another purpose was to identify data and data sources that might be available.

The literature search and the subsequent review of the documentation led to several conclusions. One conclusion was that the method of approach which used realm representations of fire growth is a reasonable one. It was also concluded that considerable work which had been completed by other researchers, could be used to develop the fire and human response dynamics. In addition, it was observed that the properties of fire realms and related processes such as products of combustion generation and spread, were known to some degree although not completely determined. The most important conclusion: While there seem to be a considerable number

Key Word Combinations Used in Computerized Literature Search

Comprehensive Engineering Index

Fire and protection and residen- or home or homes or building- or dwelling- or occupanc- or apartment-	114
Fire and protection and residen- or home or homes or dwelling- or occupanc- or apartment-	8
Fire and safety and model	0
Model or models or modeling and fire and protection and building-	6
Fire and protection and architect-	1
Fire and protection and systems analysis or system analysis	1
Radiant and fire and protection and residen- or home or homes or building- or dwelling- or occupanc- or apartment-	0
Delphi and model or models or modeling and fire	0
Fire and protection and design-	37
Fire and protection and design- and goal	0
Economic- or fire protection	3
System concept or systems concepts or systems concept and fire protection	0
Fatal- or injur- or property loss and fire	5
Fire and propagat- or growth and residen- or home or homes or building- or dwelling or occupanc- or apartment-	1
Fire and safety or protection and urban and housing	0
Floor- or support- or wall or walls or partitions or column- and fire and test	11
Fire and test- and residen-	1
Flame and spread and residen- or home or homes or building- or dwelling- or occupanc- or housing	2
Hill (with) Burton and fire	0
Fire- and test- and fiberglass or FPR	1
Human and behavior and fire-	2
Risk and analy- and fire	0
Risk and analy- and residen- or home or homes or building- or dwelling- or occupanc- or apartment-	0
Smoke propagation or generation and residen- or home or homes or building- or dwelling- or occupanc- or apartment-	1
Reliability and smoke and detection	0

National Technical Information Service

Fire and-safety and econom-	25
Fire and safety and system- and concept-	4
Fire and safety and urban and housing	23
Fire and safety and design and model-	3
Fire and test- and column- or fire and test and support-	12
Fire and test- and floor-	13
Fire and test- and partition- or fire and test- and wall-	36
Fire and test- and residen-	42
Flame and spread-	11
Fire and safety and goal- or fire and safety and objectiv-	0
Fire and Hill and Burton	1
Fire and test- and honeycomb and struct-	8
Fire and human and behavior	7
Risk and analy- and building-	6
Fire and test- and sandwich and panel-	15
Smoke and detect- and relfab-	1
Fire and safety and apartment or dwelling or home	17
Fire and safety and apartment or dwelling or home, but not fire and residential	4
Fire prevention or protection and dwelling or apartment or home	5
Building and fire and model	20
Building and fire and radiat-	22
Building and fire and surviv-	3
Fire and decision and analy-	15
Fire and fiberglass or FRP and test-	8
Fire and propagat- and resident-	6
Fire- and fatal- and resident-	0
Fire and growth and time	2
Fire and hazard and resident-	1
Fire and injur- and resident-	0
Fire and injur- and apartment or dwelling or home	0
Fire and property and loss	0
Fire and prevention or protection and automat-	16
Fire and safety and architect-	3
Fire and safety and case and stud-	2

of theoretical and empirical studies on the processes of fire and fire safety, there is, at present, no means for unifying all this material in a format wherein accurate estimations of fire development for all possible scenarios can be made. It is recognized that the Decision Tree provides a degree of that unification and can serve as a basic underlying logic.

As a result of this research, a method for evaluating fire safety in buildings which included what is known about the process involved was developed. If a process was well defined, that information was included in the method and labeled as known. If a process was not well understood, then assumptions concerning the process were made and included in the model, but clearly identified as to the source and reliability of the estimations. This evaluation led to the formulation of the approach to the problem as described in this report.

Decision Tree Coding

Coding the Decision Tree in some logical manner in order to facilitate direct application of the Tree was one of the initial research tasks. The coding scheme was designed to be compatible with the state transition model. Each DT element was given a unique code which described the position of the element, the type of FSOC it affected, how much the MPS affected the element, and what type of data (fact, theoretical, judgement, or opinion) was used to obtain inputs for this element. This scheme also allowed the Tree to be accessed by a computer program. For details, see Figure C-2.

. The coding scheme presented herein is designed to expedite the analysis, and be compatible with the state transition model. It treats each element of the Decision Tree in a unique manner and can be extended down any branch by merely adding number codes to the right as long as there are no more than nine input elements per level. It has been extended to 12 levels which, in all likelihood, will involve particular devices. It is planned that the analytical or simulation modeling will be done in FORTRAN IV on the NFPA IBM 370/125.

. The scheme is as follows:

a. Success Evaluation Factors (digits 1, 2, 3, 4)

X,000
└── General Fire Safety Objective Component

X,XX0
└── Critical Event (realm transition point)

X,XXX
└── Location of Threatened person(s) or property

b. Element Identifier (Digits 5-16)

(1) A 12 digit Element Identifier for each element on the decision tree with each digit defined as follows:

X00,000,000,000
└── 0 to signify an "And" Gate and 1 to signify an "Or" Gate of the element identified.

XX0,000,000,000
└── Prevent or Manage Impact (level 2 blocks*)

XXX,000,000,000
└── level 3

XXX,XXX,XXX,XXX
└── level 12

All elements numbered sequentially from left to right for each branch at each level.

(2) Examples:

Success Evaluation
Factors

Automatically Suppress Fire

X,XXX,121,210,000,000

Vent Fire

X,XXX,121,311,000,000
OR Gate

Provide Pre-Ignition Instructions

X,XXX,122,221,310,000

Defend Against Smoke and Gas Intrusions

X,XXX,022,212,122,000

c. HUD/MPS Field Evaluation (digits 17 through 29)

(1) Digit 17 - Impact Identifier for the General Firesafety Objective Component (FSOC) given in position 1, coded as follows:

- 0 - does not apply to this element for this FSOC
- 1 - (not used)
- 2 - applies directly to this element for this FSOC
- 3 - (not used)
- 4 - generally applies to this element for this FSOC
- 5 - (not used)
- 6 - peripherally or remotely applicable to this element for this FSOC
- 7 - (not used)
- 8 - might apply, definition unclear
- 9 - (not used)

(2) HUD/MPS Reference Sentence (digits 18-29)

Example 1: 507-6.1 Bulk Sealing Compound

coded 0507-06-01-00-00

Example 2: 507-6.1.f. Polyurethane Compounds (Polyurethane Prepolymers)

coded 0507-06-01-00-06 (f is the sixth letter in the alphabet and the last digit in this coding scheme)

d. Success Probability Estimate (digits 30-41) - probability estimate for Factors given in 1 through 4 for element shown in 5 through 16.

Probability may be computed (estimated for the HUD/MPS) for Factors in 1, 2, 3, 4. If it meets the HUD/MPS, what is the probability of success for this Factor? For example: 99.9990000000.

e. Confidence Levels (Digits 42 and 43). These will designate the source and, thereby, a measure of the level of confidence in the quality of the data.

00 Laws of Science

01 Fundamental theories founded in a high level of scientific evidence

.
.

.

04 Theories long accepted and applied in fire protection field with no evidence of disproof

.
.

.

10 Data-Based Information

11 From fire loss data - verified and unbiased

12 From fire loss data - believed to be unbiased (not verified)

13

.
.

.

19 From fire loss data - believed to be biased and unconfirmed, but "all we've got"

20 Fire Test Results

21 From fire test data - sound, reproducible results

22

.
.

.

29 From fire test data - abstract and questionable conclusions, not reproducible

30 Emperical Testing/Data

31

.
.

.

40 Professional Judgement

41 Judgemental - a representative, unbiased cross-section of
fire protection practitioners and results "averaged" via....
(method)

42

.

.

.

48 Judgemental - a single fire protection practitioner surveyed -
one considered "qualified" in scope of the question

49 Judgemental - a single fire protection practitioner surveyed -
one not specialized in the subject in question

50

51

60 Nonprofessional Opinion

60 Judgemental - a sampling of a cross-section of society was
surveyed without bias

61

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.

.

69 Judgemental - a single "citizen on the street" randomly
interviewed

70

71

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Boolean Indicated Cut Sets (BICS)

As part of the study of the Decision Tree, the logic of the Tree was analyzed using a logic called "cut-set" adapted from the work of Brown and Chatterjee.⁽¹¹⁾ A cut-set is a set of basic conditions (Tree elements) whose occurrence implies success in meeting the goal, i.e., firesafety objectives. These cut-sets are known as Boolean Indicated Cut Sets (BICS). A cut-set is called minimal if the number of elements cannot be further reduced and still insure goal achievement. The BICS were determined for the Decision Tree and, from that analysis, the logical consistency and lack of redundancy in the Tree was confirmed. In a logically consistent tree, each branch of elements (under variable conditions of other branches) can influence the outcome element. Thus, the application of the BICS helped the project staff understand the logic of the DT, gain confidence in the soundness of the Tree, and allow an examination of the firesafety implications of grouped elements (S). The BICS may again prove useful when the Tree has been modified to reflect the effect of Tree elements or combinations thereof on FSOC in the various fire realms.

APPENDIX D

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Architectural Approaches to Fire Safety," Prof. Richard Bender, University of California, Berkeley, California 94720, Dept. of Architecture

Fire Safety in Urban Housing," Prof. R. B. Williamson, Department of Civil Engineering, University of California, Berkeley, California 94720

Fire Propagation Along Solid Surfaces," Prof. F. A. Williams, Dept. of Applied Mechanics & Engineering Sciences, University of California, San Diego, La Jolla, California 92037

Prediction of Fire Hazard in Buildings," Prof. P. Durbetaki, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332

Properties of Combustion Products from Building Fires," Prof. B. T. Zinn, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332

Home Fire Project," Prof. H. W. Emmons, Department of Mechanical Engineering, Harvard University, Cambridge, Massachusetts 02138

Fire Problems Res. & Synthesis," Prof. R. W. Fristrom, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland 20910

Program for Design Concepts," Harold E. Nelson, National Bureau of Standards, Department of Commerce, Gaithersburg, Maryland

Fire & Smoke Spread in Corridors," Prof. J. L. Novotny, Dept. of Aerospace Mechanical Engineering, University of Notre Dame, South Bend, Indiana 46656

Physiological & Toxicological Aspects of Smoke Produced During the Combustion of Polymeric Materials," Prof. Irving Einhorn, Dept. of Material Sciences Engineering, University of Utah, Salt Lake City, Utah 84112

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Research Practice Needs," Conference on Fire Safety for Buildings, Airlie House, Airlie, Virginia July 18-20, 1973

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